APPENDIX A: ACRONYMS AND ABBREVIATIONS

ABS	Australian Bureau of Statistics
AEMI	Australian Emergency Management Institute
AEP	annual exceedence probability
AFLD	air field
AGSO	Australian Geological Survey Organisation
AHD	Australian height datum
ANU	Australian National University
ARI	average recurrence interval
ASDI	Australian spatial data infrastructure
AWS	automatic weather stations
B.P.	before present
BPA	Beach Protection Authority
C	Celsius
CBD	central business district
CCD	census collection district
Comms	telecommunications
CQU	Central Queensland University
cumec	cubic metres per second
DDC	disaster district coordinator
DEM	digital elevation model
DES	(Queensland) Department of Emergency Services
DME	(Queensland) Department of Mines and Energy
DNR	(Queensland) Department of Natural Resources
EDRI	earthquake disaster risk index
e.g.	for example
EMA	Emergency Management Australia
ENSO	El Niño / Southern Oscillation
EPA	Environmental Protection Agency
FEMA	(US) Federal Emergency Management Agency
ft	feet
FWC	flood warning centre
GH	gauge height
GIS	geographic information system
GMS	global meteorological satellite
ha	hectares
HAT	highest astronomical tide
hPa	hecto-pascals
HQ	headquarters
hr(s)	hour(s)
IDNDR	International Decade for Natural Disaster Reduction
in	inches
IPA	Integrated Planning Act
IPCC	Intergovernmental Panel on Climate Change
IPO	Inter-decadal Pacific Oscillation
km	kilometres
km/h	kilometres per hour
LAT	lowest astronomical tide
LDC	local disaster committee
LPG	liquid petroleum gas

m	metres
max	maximum
MDR	mean damage ratio
min	minimum
mm	millimetres
MPI	maximum potential intensity
m/sec	metres per second
MEOW	maximum envelope of water
NOAA	(US) National Oceanographic and Atmospheric Administration
PGA	peak horizontal ground acceleration
QPS	Queensland police service
RACQ	Royal Automobile Club of Queensland
SCAG	South Connors-Auburn-Gogano Project
SCDO	State Counter Disaster Organisation
SEIFA	socio-economic indexes for areas
SES	State Emergency Service
SLA	statistical local area
SOI	Southern Oscillation Index
SST	sea surface temperature
TCCIP	Tropical Cyclone Coastal Impacts Program
TCWC	Tropical Cyclone Warning Centre
temp	temperature
UHF	ultra high frequency
UNDRO	United Nations Disaster Relief Organisation
UNEP	United Nations Environment Program
UPS	uninteruptable power supply
VHF	very high frequency
WMO	World Meteorological Organisation

APPENDIX B: MACKAY *BUILDING* DATABASE FORMAT

The following list provides details of the table structure employed for the *BUILDING* database.

UFI	Integer	
Feature	Character	35
Address	Character	35
Suburb	Character	25
Type	Character	2
Fl_ht	Decimal	3,1
Gd_ht	Decimal	6,2
Storeys	Decimal	2,0
Walls	Character	2
Roof	Character	2
Ro_shape	Character	2
Ro_pitch	Character	2
Windows	Character	2
Plan_reg	Character	2
Vert_reg	Character	2
Age	Character	2
Units1	Decimal	2,0
Units2	Decimal	2,0
Units3	Decimal	3,0
Status	Character	2
Comments	Character	35
Lot_plan	Character	15
Longitude	Decimal	9,4
Latitude	Decimal	9,4
Std50	Character	2
Std100	Character	2
Std500	Character	2
Std1000	Character	2
Std10000	Character	2
V_zone	Decimal	4,2
Site_class	Character	2

NOTE: in the following description, attributes in **bold** need to be collected in the field; attributes *underlined* and in italics are typically derived from council data but need to be verified in the field; attributes in plain text are derived from other sources.

A brief explanation of the thresholds adopted is also provided where appropriate.

The first group of fields provide for unique identification and description of the feature.

UFI Unique Feature Identifier - unique number for each record. Computer generated.

Feature Name of the feature or its occupant or use as indicated by signs on or at the feature.

Address Street address of the feature including number and street name.

Suburb Suburb, town or locality name.

Type Major activity conducted at feature as identified from field observation. The following broad activity groups have been used and features displayed with the symbols indicated in the following table:

Table B1: Classification of feature use for Mackay

CODE	CLASSIFICATION	SYMBOL	COMMENTS
P	**P**ublic safety - police, fire, ambulance, SES, defence, etc.	12pt solid cross, black	*Sensitive facilities* related to the provision of emergency response
S	**S**torage and transport - features that support road, rail, air and sea transport and storage (eg warehouses)	12pt solid dot, orange	*Sensitive facilities* that contribute significantly to community sustainability
L	**L**ogistics - bulk supplies of fuel, gas & food including supermarkets and service stations	12pt solid dot, yellow; 18pt solid dot yellow is used for major complexes	*Sensitive facilities* that contribute significantly to community sustainability
D	**D**octors and other health services - hospitals, nursing homes, clinics, dentists, etc.	12pt solid cross, green	*Sensitive facilities* that provide all forms of health service
U	power **U**tilities - generation, distribution and service facilities	12pt solid star, black	*Sensitive facilities* that provide, manage, or service power supplies
W	**W**ater supply and sewerage utilities - above ground storage, treatment, pumping, etc.	12pt solid dot, light blue	*Sensitive facilities* that store, treat, or reticulate water and sewerage services, or manage and service those utilities
T	**T**elecommunications - radio, telephone, TV, etc.	12pt asterisk, black	*Sensitive facilities* that provide, manage, or service communications services
A	**A**ccommodation - commercial (non private) accommodation such as hotels, motels & resorts	10pt solid square, red	*Special risks* associated with commercial accommodation where concentrations of people are found - typically short term accommodation
B	**B**usiness - commercial and professional facilities such as shops, offices, etc.	10pt solid square, yellow	*Special risks* associated with shopping centres and other places of business
E	**E**ducation - schools, TAFE, convents, child care centres, etc.	12pt 'flagged building', red	*Special risks* associated with concentrations of children

R	**R**ecreation facility - sporting clubs, grandstands, etc.	10pt solid square, green	*Special risks* associated with periodic concentrations of people
I	**I**ndustry - manufacturing and processing industries such as sawmills, sugar mills, cement plants, ship building, etc.	12pt solid triangle, yellow	*Special risks* associated with either processes and materials used and/or concentrations of people
H	**H**ouses - private, detached houses only	9pt solid diamond, black	Detached houses only
F	**F**lats - includes all multi-occupant private dwellings including units, town houses and apartments	9pt solid diamond, red	All forms of private accommodation other than detached houses - includes self contained holiday units, or apartments typically used for longer stays than motels, resorts, etc.
C	**C**ommunity facilities - churches, halls, public toilets, libraries, scout huts, monuments, etc.	12pt solid dot, purple	Mainly non-government facilities providing direct service to the community
G	**G**overnment facilities - offices, depots, etc. of all levels of government	12pt solid dot, dark blue	Facilities from which government services are provided or administered
Z	Miscellaneous features – eg. sheds, car parking structures, etc.	10pt open square, black	Generally minor or low use features
O	**O**pen space - features such as parks, reserves, etc.	10pt open green square	Land without buildings used for parks, reserves, etc.
V	**V**acant land	9pt solid circle, pale green	Used only for land that is intended for buildings.

The next group of attributes describe aspects of the building that contribute to its vulnerability to a range of hazards.

Fl_ht Height of the floor above ground level. Estimated to the nearest 10 cm. A value of 0.3 indicates a slab construction. A default value of 0.3 is also used where field observed data are not available

Gd_ht Height of the ground (above the Australian Height Datum - AHD) at the centre of the feature. Derived from DEM.

Storeys The number of storeys above ground.

Walls Construction material used for the walls of a feature. The following codes are used:

B brick, masonry or stone
C concrete block
P precast concrete slab

R reinforced concrete frame
T timber
F fibro
M metal

Roof Construction material used for the roof. The following codes are used:

T tiles
F fibro
M metal
C concrete

Ro_shape Predominant roof shape with the following codes:

H hip ended
G gable ended

Flat roofs are automatically gable ended.

Ro_pitch Roof pitch with the following codes:

H high (>1:4 slope)
L low (< 1:4 slope)
F Flat

Tiled roofs are automatically high pitch. The thresholds were recommended by Mr Greg Reardon of the James Cook University Cyclone Testing Station to differentiate slopes that will have greater (low slope) or lesser (high slope) 'lift' from strong winds.

Windows The relative size of individual windows with the following codes:

L large windows or glass doors (i.e. greater than 75% of wall height occupied by glass in a given window or door)
S small windows
N no windows
O open walls

Plan_reg Plan regularity - an observation of the plan configuration geometry regularity of the building based on Figure A1 of AS1170.4-1993 (*Earthquake loads*) with the following codes:

R regular (essentially square or rectangular)
I irregular ('T', 'L', 'U' or other irregular shape)
U unknown, not observed

If collateral evidence exists of plan irregularity other than geometric (eg. mass resistance eccentricity or discontinuity of diaphragm stiffness) then the appropriate code should be used with details placed in the *Comments* field.

Vert_reg regularity

Vertical regularity - an observation of the vertical configuration geometry and stiffness ratio (e.g 'soft storey' construction) based on Figure A2 of AS1170.4-1993 (*Earthquake loads*) with the following codes:

R	regular
I	irregular
U	unknown, not observed

'Queenslander' style houses or 'six pack' blocks of flats in which the main mass of the building is elevated on posts or piles and the open under-space occupied by garages etc. should be coded as *Irregular*. If collateral evidence exists of other forms of vertical irregularity (e.g. in mass ratio irregularity caused by a roof-top swimming pool) then the appropriate code should be used with details placed in the *Comments* field.

Age

Estimated date of construction with the following codes:

A	built since 1995
B	built between 1985 and 1994
C	built between 1975 and 1984
D	built between 1965 and 1974
E	built between 1955 and 1964
F	built before 1955

Note: most buildings coded 'C' are simply those built before 1985

In general terms these dates reflect significant changes in building regulations and/or practice (e.g. first wind loading code introduced in 1975, upgraded in 1984-85; earthquake loading code for domestic structures effective by 1995; brick veneer construction techniques became popular after 1955).

The following fields describe the number of dwelling units contained in multi-resident features such as flats, apartments and units, or businesses in commercial complexes.

Units1

The number of separate occupiable dwelling units (discrete flats, apartments, town houses, motel/motel suites, etc.) with the lowest dwelling space (not including laundries, garage, etc.) located on the ground floor (level 1). Estimated to be at least 95% accurate where recorded. Typically based on a count of letterboxes; some data for commercial accommodation taken from material provided by the operator of the feature or from the RACQ accommodation guide.

Units2

The number of separate occupiable dwelling units with the lowest dwelling space located on the second level. Other parameters as for *U1*.

Units3

The number of separate occupiable dwelling units with the lowest dwelling space located on the third or higher levels. Other parameters as for *U1*.

The following fields provide for additional data and for an assessment of the general data quality.

Status An indication of the source of the detailed data with the following codes:

O	observed - field collected
E	estimated - based on sample or cursory observation
P	interpreted from aerial photos
D	data taken from the work of 'Dingle' Smith in 1993
U	unknown - yet to be collected

Comments Note field for added information on the feature derived from field notes.

The following fields provide linkage to other databases such as rates or the DCDB.

Lot_plan The lot-on-plan description of the parcel of land on which the feature object is located. Derived by computer from the DCDB and/or council data.

Longitude Decimal longitude derived by computer from the feature object location using AGD84 as the datum.

Latitude Decimal latitude derived by computer from the feature object location using AGD84 as the datum.

The following fields provide information related to hazard exposure. They have been derived from other data including the DEM and floor height.

Std50 ***Exposure of building to a 2% AEP storm tide where:***

A	more than 1 m over floor level
B	water over floor level but less than 1 m
C	water on property but not over floor level

Std100 Exposure of building to 1% AEP storm tide with coding as for *Std50*

Std500 Exposure of building to 0.2% AEP storm tide with coding as for *Std50*

Std1000 Exposure of building to 0.1% AEP storm tide with coding as for *Std50*

Std10000 Exposure of building to 0.01% AEP storm tide with coding as for *Std50*

V zone Distances from the shoreline in 150 m increments. Values are 0.8 = 0 to 150 m, 0.4 = 150 to 300 m; and, 0.2 = 300 to 450 m.

APPENDIX C: ELEMENTS AT RISK DETAILS

Table C1: Variables used in the SEIFA *Index of Socio-Economic Disadvantage* (ABS, 1998b)

Variables with weights between 0.2 and 0.3:

- persons aged 15 and over with no qualifications (%);
- families with income less than $15 000 (%);
- families with offspring having parental income less than $15 600 (%);
- females (in labour force) unemployed (%);
- males (in labour force) unemployed (%);
- employed females classified as 'Labourer & Related Workers' (%);
- employed males classified as 'Labourer & Related Workers' (%);
- employed males classified as 'Intermediate Production and Transport Workers' (%);
- persons aged 15 and over who left school at or under 15 years of age (%);
- one parent families with dependent offspring only (%); and,
- households renting (government authority) (%).

Variables with weights between 0.1 and 0.2:

- persons aged 15 and over separated or divorced (%);
- dwellings with no motor cars at dwelling (%);
- employed females classified as 'Intermediate Production & Transport Workers' (%);
- employed females classified as 'Elementary Clerical, Sales & Service Workers' (%);
- employed males classified as 'Tradespersons' (%);
- persons aged 15 and over who did not go to school (%);
- Aboriginal or Torres Strait Islanders (%);
- occupied private dwellings with two or more families (%); and,
- lacking fluency in English (%).

Table C2: Variables used in the SEIFA *Index of Economic Resources* (ABS, 1998b)

Variables with weights between 0.2 and 0.4:

- households owning or purchasing dwelling (%);
- dwellings with four or more bedrooms (%);
- families with family structure other than two parent or single parent with dependent offspring or consisting of a couple only, and income greater than $77 999 (%);
- families consisting of a couple only, and with income greater than $62 399 (%);
- families consisting of a single parent with dependent offspring, with income greater than $31 199 (%);
- mortgage greater than $1300 per month (%); and,
- rent greater than $249 per week (%).

Variables with weights between 0 and 0.2:

- households purchasing dwelling (%);
- households owning dwellings (%);
- dwellings with three or more motor cars (%); and,

- average number bedrooms per person (%).

Variables with weights between -0.2 and 0:

- households in improvised dwellings (%);
- households renting (government authority) (%);
- households renting (non-government authority) (%);
- dwellings with one or no bedrooms (%);
- rent less than $74 per week (%); and,
- families consisting of a single parent with dependent offspring, with income less than $15 600 (%).

Variables with weights between -0.3 and -0.2:

- families consisting of a couple only, and with income less than $15 600 (%);
- families with family structure other than two parent or single parent with dependent offspring or consisting of a couple only, and income less than $26 000 (%);
- families consisting of a two parent family with dependent offspring, and income less than
  $26 000 (%); and,
- dwellings with no motor cars (%).

Table C3: Mackay Schools

SCHOOL	ADDRESS	LOCALITY	STUDENT NUMBERS			STAFF NUMBERS
			PRE[1]	PRI[2]	SEC[3]	
Andergrove State	Fernleigh Avenue	Andergrove	94	674		38
Beaconsfield State	Nadina Street	Beaconsfield				
Bucasia State Primary	Kemp Street	Bucasia	27	238		14
Dundula State	Main Street	Bakers Creek	36	107		5
Eimeo Road Primary	Eimeo Road	Rural View	30	278		13
Fitzgerald State	Norris Road	North Mackay	82	640		33
Glenella Primary	Hill End Road	Glenella	48	141		6
Holy Spirit College	Baxter Drive	Mt Pleasant				
Kewarra Special	Mansfield Drive	Beaconsfield		25		6
MacKillop Catholic	Nadarmi Drive	Andergrove				
Mackay Central State	Alfred Street	Cent Mackay	41	220		12

Mackay Christian College	Quarry Street	North Mackay				
Mackay North State High	Burgess Street	North Mackay			1131	77
Mackay North State Primary	Evens Avenue	North Mackay		365		26
Mackay 7th Day Adventist	Milton Street	Cent Mackay				
Mackay Special	Goldsmith Street	East Mackay				4
Mackay State High	Milton Street	South Mackay			932	69
Mackay West Primary	Brooks Street	West Mackay	86	713		42
Northview Primary	Pioneer Street	Mt Pleasant	41	309		19
OLMC High	Penn Street	South Mackay				
OLMC Primary	Penn Street	South Mackay				
Pioneer State High	Bedford Street	Andergrove			705	56
St Francis Xavior Primary	Bridge Road	West Mackay				
St Josephs Primary	Canberra Street	North Mackay				
St Patrick's College	Gregory Street	Cent Mackay				
Slade Point Primary	Slade Point Road	Slade Point	50	358		19
Victoria Park State	Goldsmith Street	East Mackay	116	573		31
Victoria Park Special	Shakespeare Street	Cent Mackay				
Whitsunday Anglican	Celeber Drive	Andergrove				

Where 1 = preschool, 2 = primary school, and 3 = secondary school.

NOTE: The enrolment and teacher statistics for state schools were derived from Department of Education data for 1996. No comparable data are available for non-government schools. State preschools are typically (but not exclusively) co-located with their respective primary school.

Table C4: Mackay Child Care Centres

CENTRE	ADDRESS	SUBURB
Beach Kidz Ch ild Care & Education Centre	Eimeo Road	Eimeo
Billabong Kindyland	Hamilton Street	North Mackay
Billabong Kindytown	Shakespeare Street	East Mackay

Birralee Child Care Centre	Pompey Street	South Mackay
Bucasia Kindergarten Association	Fisher Street	Bucasia
Busy Kids Childrens Education Centre	Celeber Drive	Andergrove
Hot Tots Education Centre	Paget Street	West Mackay
Kookaburra Child Care	Bedford Road	Andergrove
Koolyangarra Childcare Centre	River Street	Central Mackay
Mackay Child Care Centre	River Street	Central Mackay
Mackay Cubbie House Childcare	Beaconsfield Road	Beaconsfield
Mackay Family Day Care	Wellington Street	Central Mackay
Mackay Kindergarten	Shakespeare Street	West Mackay
Pioneer Pre School	High Street	North Mackay
St Francis Xavior Day Care Centre	Holland Street	West Mackay
Snugglepot Kindeland	Grendon Street	North Mackay
YMCA Playmates Childcare Centre	Macalister Street	Central Mackay

Table C5: Variables used in the SEIFA *Index of Education and Occupation* (ABS, 1998b)

Variables with weights between 0.2 and 0.4

- employed males classified as 'Professionals' (%);
- employed females classified as 'Professionals' (%); and,
- persons aged 15 and over at a college of advanced education or university (%).

Variables with weights between 0 and 0.2

- employed males classified as 'Associate Professionals' (%);
- employed females classified as 'Advanced Clerical & Social Workers' (%);
- employed males classified as 'Advanced Clerical & Social Workers' (%); and,
- employed males classified as 'Intermediate Clerical, Sales & Service Workers' (%).

Variables with weights between -0.2 and 0

- employed females classified as 'Tradespersons' (%);
- employed males classified as 'Tradespersons' (%);
- employed females classified as 'Elementary Clerical, Sales & Service Workers' (%); and,
- employed females classified as 'Intermediate Production & Transport Workers' (%).

Variables with weights between -0.4 and -0.2

- employed males classified as 'Intermediate Production & Transport Workers' (%);
- employed females classified as 'Labourer & Related Worker' (%);
- employed males classified as 'Labourer & Related Worker' (%);
- males (in labour force) unemployed (%);
- females (in labour force) unemployed (%);

- person aged 15 and over who left school at or under 15 years of age (%); and,
- person aged 15 years and over with no qualifications (%).

Table C6: **Mackay Community Organisations**

SPORTS AND HOBBIES REPRESENTED	SERVICES REPRESENTED
Archery	Aboriginal and Torres Strait communities
Athletics	Aged care services
Baseball	Apex
Basketball	Boy Scouts and Girl Guides
Bicycle racing	Chamber of Commerce and Industry
Bird fanciers	Conservation and environmental groups
Bowling	Country Women's Association
Boxing	Drug and alcohol support groups
Bridge	Eisteddfod
Bush walking	Endeavour Foundation
Cars and motor racing	Genealogical groups
Chess	Guide dogs for the blind
Cricket	Historical Society
Croquet	Hospital auxiliaries
Dance	Independent retirees
Dog coursing and kennel	Jaycees International
Fishing	Legacy
Flying and gliding	Lifeline
Football (all codes)	Lions International
Gem and lapidary	Marriage guidance
Golf	Masonic and other lodges
Gymnastics	Meals on wheels
Hockey	Neighbourhood and community associations
Lawn Bowls	Paraplegic and quadriplegic association
Life saving and surfing	Police and Citizens Youth Club
Martial arts	Probus
Netball	Professional and business groups
Photography	Queensland keep fit
Pottery	Quota
Racing, hunting and pony	Red Cross
Roller skating and roller hockey	Returned Services League
Scuba diving	Rotary
Shooting	Rotaract
Softball	RSPCA
Squash	St Johns Ambulance
Swimming	SES
Table tennis	Sexual assault service
Tennis	Soroptimists International
Tenpin bowling	South Sea Islanders Association
Vigaro	Toastmasters
Volleyball	U3A
Wheelies and disabled sport	Women's Information and Referral
Wood turning	YMCA
Yachting and boating	YWCA

Yoga	Zonta International

Table C7: **Mackay Critical Facilities**

FACILITY	STREET	SUBURB	HAZARDOUS
ABC Studios	River Street	Central Mackay	
ABC Radio Transmitters (4QA)	Slade Point Road	Mackay Harbour	
Airport runways	Milton Street	South Mackay	
Airport Control Tower	Milton Street	South Mackay	
Airport Rescue and Fire Service	Milton Street	South Mackay	
Alcorn's Bakery	Bedford Street	Andergrove	
Ambulance Station Mackay	Alfred Street	Central Mackay	
Ambulance Station Mt Pleasant	Lauchlan Street	Mount Pleasant	
Ampol Fuel Depot	Harbour Road	Mackay Harbour	major
Boral Gas Depot	Harbour Road	Mackay Harbour	major
BP Fuel Depot	Graeme Heggie Road	Mackay Harbour	major
Campbells Cash & Carry	Victoria Street	Central Mackay	yes
Canelands Shopping Town	Mangrove Road	Central Mackay	yes
Caltex Fuel Depot	Harbour Road	Mackay Harbour	major
Country Bake Bakery	Bridge Road	West Mackay	
CSR Bulk Sugar Terminal	George Bell Drive	Mackay Harbour	yes
District Police HQ Mackay	Sydney Street	Central Mackay	
Fire Station Mackay	Alfred Street	Central Mackay	
Fire Station North Mackay	Harbour Road	North Mackay	
Fire Station Northern Beaches	McHugh Street	Bucasia	
Grain Silos	George Bell Drive	Mackay Harbour	yes
INCITEC	Harbour Road	Mackay Harbour	major
James Borthwick & Sons	Connors Road	Bakers Creek	yes
Mackay Base Hospital	Bridge Street	West Mackay	yes
Mackay City Council Centre	Gordon Street	Central Mackay	
Mackay City Council Works Depot	Bedford Road	Andergrove	major
Mackay Port Facilities	Harbour Road	Mackay Harbour	yes
Mackay Railway Yards	Boundary Road	Paget	yes
Mackay SES District HQ	River Street	Central Mackay	
Mackay SES Local HQ	Cemetery Road	West Mackay	
Mata Hospital	Gordon Street	Central Mackay	yes
Mobil Fuel Depot	Graeme Heggie Road	Mackay Harbour	major
Mount Bassett Weather Station	Mount Bassett Drive	Mackay Harbour	minor

Mount Pleasant Shopping Centre	Philip Street	Mount Pleasant	yes
Northern Food Wholesalers	Heidi Street	Paget	yes
Pauls Ltd	Evans Avenue	North Mackay	yes
Pioneer Valley Hospital	Raymond Crocker Av	Mount Pleasant	yes
Police Station Mackay	Brisbane Street	Central Mackay	
Racecourse Mill	Peak Downs Highway	Racecourse	yes
Radio 4CRM Studio	Victoria Street	Central Mackay	
Radio 4MK Studio	Sydney Street	Central Mackay	
Radio 4MK Transmitter	Mt Bassett Cemetery Rd	Mackay Harbour	
Seafresh Products	River Street	Central Mackay	yes
Searaker	River Street	Central Mackay	yes
Sewerage Treatment Plant	Mt Bassett Cemetery Rd	Mackay Harbour	yes
Shell Fuel Depot	Harbour Road	Mackay Harbour	major
Telephone Exchange Mackay	River Street	Central Mackay	yes
Telephone Exchange Paget	Bruce Highway	Paget	minor
TEN TV Studio	Wellington Street	Central Mackay	
Water Treatment Plant	Nebo Road	West Mackay	yes
WIN TV Studio	Gregory Street	Central Mackay	

Notes:

major = nature and quantity of hazardous materials poses a major potential threat
yes = nature and quantity of hazardous materials poses a moderate threat
minor = nature and quantity of hazardous materials poses a minor threat

APPENDIX D: METHODOLOGY FOR ASSESSING RELATIVE COMMUNITY VULNERABILITY

Ken Granger

In Chapter 1 we described the approach adopted by the *Cities Project* to assess community risk. At the heart of that approach is the view of total risk as being the outcome of the interaction between a hazard phenomenon, the elements at risk in the community and their degree of vulnerability to that impact. The relationship was summarised in the expression:

$$\textbf{Risk}_{\textbf{(Total)}} = \textbf{Hazard x Elements at Risk x Vulnerability}$$

In Chapters 2 and 3 we described individual aspects of the community and the contribution they make to community vulnerability. We also presented an assessment of their relative contribution to the overall community vulnerability of Mackay. In this Appendix we describe the methodology we have developed to produce that relative assessment and the philosophy that underpins it.

The Challenge

Over the past four or five years a large amount of high resolution data has been accumulated on the hazard phenomena, buildings, infrastructure and the people of Mackay. Whilst those data provide a detailed quantitative description of specific aspects of the city's risk environment, they do not, of themselves, provide an adequate measure of overall community vulnerability. Nor do they individually reflect the relative levels of vulnerability across the city. We considered it to be highly desirable, however, to be able to identify those parts of the city that would provide a potentially disproportionate contribution to community risk, regardless of the hazard involved, because of the number and nature of the elements at risk they contained.

The challenge, then, is to develop a measure, or index, that enables us to rate suburbs on the basis of their contribution to overall risk.

Vulnerability Indexes

There is little in the risk management or disaster management literature to use as a guide to construct such an index. Whilst the two workshops held at the Australian Emergency Management Institute (AEMI) at Mount Macedon in April and September 1995 contributed significantly to our understanding of vulnerability as a concept, they were not conclusive where the development of a 'vulnerability index' was concerned.

One of the few worked-through examples of a 'risk index' we have found is the Earthquake Disaster Risk Index (EDRI) approach developed by Dr Rachel Davidson (1997), now at the University of North Carolina at Charlotte. EDRI is being used to compare the earthquake risk in some 72 cities around the world as part of the *Understanding Urban Seismic Risk Around the World* Project.

The philosophy behind EDRI is similar to that which underpins the *Cities Project*. It is summarised by Davidson and Shah (1998) in the following terms:

Using a holistic approach, the EDRI attempts to measure the risk of an urban earthquake disaster. This is a broader concept than just the expected frequency of future earthquakes, or even their expected impact in terms of the number of deaths, injuries, or damaged buildings. In assessing earthquake disaster risk, the economic, social, political, and cultural context of the earthquake hazard plays a role too. An earthquake disaster is considered to be a function of not only the expected physical impact of future earthquakes, but also the capacity of the affected city to sustain that impact, and the implications of that impact to the city and to world affairs.

EDRI is based on data considered to 'measure' the contribution to overall risk under five factors described as follows:

- ***Hazard*** *- Severity, extent, and frequency of the geological trigger phenomenon to which the city may be subject.*
- ***Exposure*** *- Size of the city. Number of people and physical objects, and the amount and type of activities they support.*
- ***Vulnerability*** *- How easily the exposed people, physical objects, and activities may be affected in the short or long-term.*
- ***External Context*** *- How impact within a city affects people and activities outside the city.*
- ***Emergency Response and Recovery Capability*** *- How effectively and efficiently a city can reduce the impact of an earthquake through formal, organised efforts made specifically for that purpose.*

Davidson's index is built on a range of weighted 'indicator' values that are combined to provide a standard measure by which to compare 'earthquake disaster risk' of individual cities.

The urban geography literature of the 1960's also contains examples of research aimed at classifying areas within cities to reflect particular features such as socio-economic status. Berry and Horton (1970), for example, provide a good overview of this research. Most of these examples rely on statistical analysis such as factor analysis and analysis of variance.

The approach we have developed here is similar in most basic respects to both EDRI and the classic geographic numerical taxonomy studies. It differs from EDRI, however, in two main ways. First, it is being used to assess the risk posed by a range of hazards across a single city, and second, we have not been constrained by selecting indicators that are available 'universally'. It differs from the multi-variate statistical techniques in that it was undertaken using MapInfo and Microsoft Excel rather than specialised statistical analysis software. This computationally less demanding approach was felt to be important given that it is intended for use by local governments and others responsible for undertaking risk assessments at the local level.

We have also constructed it to better 'fit' our risk assessment process described in Chapter 1, especially the 'five esses' approach to the analysis of vulnerability.

The approach we have developed was first used in the Cairns case study (Granger and others, 1999). In the Cairns study we chose to present the analyses at the suburb level given that most members of the community already identify themselves at home and at work with a suburban locality. For Mackay, however, we have adopted a different strategy, namely constructing the analysis at the level of the CCDs used in the 1996 national census. These units typically contain approximately 200 households. We have chosen this approach for two reasons. First, the suburb boundaries for Mackay do not match with CCD boundaries so it was difficult to translate the census-derived statistics to the suburban level. Second, we wished to test and demonstrate the utility of using a much higher resolution of risk assessment than provided by the suburban-level approach. In the Mackay study area there are 27 suburbs and 96 CCDs.

Assumptions

Because we are interested in showing the relative importance of each CCD to overall community vulnerability, it was assumed that the most appropriate statistic to use would be the rank of the CCD in each measure. The use of rank is not without its problems. Inclusion of several variables that are highly correlated or indeed derived from the same basic statistic will obviously bias the outcome. Similarly, the inclusion of variables that have little, if any, bearing on community vulnerability could also distort the results. We feel, however, that with the careful selection of variables, rank is an appropriate statistic to reflect the relative significance of CCDs.

We have not, as yet, conducted a systematic sensitivity analysis, though our observations during the development of the techniques with the Cairns study, and subsequently with this Mackay study, suggest that whilst relatively minor changes to the inclusion of variables may cause some variation to individual ranks, the overall results remain largely consistent. A detailed sensitivity analysis and comparison of the Cairns and Mackay methods has been commissioned as part of our ongoing methodology development process.

The Setting

Given that the variables within the 'setting' group of elements at risk (see Chapter 1 and Chapter 2) relate mainly to external factors (e.g. the source of power supply), or to factors that apply equally across all suburbs (e.g. jurisdictions), only four variables were selected.

Terminal facilities: The facilities that provide the interface between the study area and the rest of the world are extremely important. The facilities selected for inclusion are those that facilitate the entry of goods or services into the study area (e.g. the key power substations and the fuel depots), export of goods from the study area (e.g. the bulk sugar and grain terminals) and bi-directional facilities (e.g. the airfield and rail-freight terminal). The facilities identified as terminals are listed in Table 2.3. In determining suburb ranks, those facilities that have both an import and export function (e.g. the airport) were weighted by a value of two, whilst those with either import (e.g. fuel depot) or export functions (e.g. sugar terminal) were given a weighting only of one.

Population: Clearly the most significant element at risk is the population of the community. CCDs were ranked on the basis of their total population. The absolute population totals ranged from a high of 1560, to a low of 90 and a mean of 613 persons. CCDs were ranked from highest value to lowest value.

Population density: To balance the absolute population figures, which are sensitive to CCD boundary design, we have also included population density taken as the number of people per square kilometre. This is sensitive to CCD area (a function of boundary design). The density ranges from a high (rank 1) of 3280, to a low (rank 96) of nine, with a mean of 1244.

Masculinity: The gender ratio measured in terms of the number of males for every 100 females provides a crude measure of the structure of the population. At the CCD level it appears to be sensitive to identifying institutions such as nursing homes and boarding schools where highly skewed gender ratios can be expected. The values range from 76 males per hundred females to 156 males per hundred females with a mean of 99.7. CCDs were ranked from lowest value (least masculine) to highest value (most masculine) on the possibly questionable, but widely held assumption, that males are more resilient than females.

Suburb-level composite: A composite view of the setting group variables at the suburb, rather than CCD level, was produced to simplify the analysis of total risk posed by each hazard. This composite was constructed by summing the ranks of each CCD that fell completely or partly within each suburb boundary. That sum was then ranked to produce the map contained as Figure 3.20 and listed in Table 3.9.

Shelter

Eight variables were selected to represent the shelter group of elements at risk.

Houses: Houses provide the most widespread form of shelter in the community, and, consequently, they are considered to make a specific contribution to community vulnerability. CCDs were ranked on the number of houses, included in the Mackay *BUILDING* database (Appendix B), that were within their boundary. This source was chosen over the house totals contained in the 1996 census data provided in ABS (1998a) because it was considered to be more current by three years. The totals ranged from a high of 507 (rank 1) to a low of one (rank 96), with a mean of 185.

Average house occupancy: CCDs were ranked on the average number of people living in separate houses at the 1996 census. This is a reasonable measure of household size. Values ranged from 3.55 people down to 2.31 persons, with a mean of 2.88. CCDs were ranked from highest value to lowest value.

Flats: Flats are the second most significant form of shelter. The total number of multi-occupant buildings classified as flats in the Mackay *BUILDING* database contained in each CCD was used rather than the number of flats and other similar forms of accommodation contained in the census data. The census data provides tallies of the number of individual dwelling units rather than buildings, so for consistency and currency the building data was used in preference. Totals ranged from 60 (rank 1) to 0 (rank 85), with a mean of 9. CCDs were ranked from highest value to lowest value.

Average flat occupancy: Household size in flats was assessed from the average number of people living in flats in each CCD. These data were also taken from the 1996 census and relate to the occupancy of individual flats rather than the occupancy of buildings. For the CCDs with flats, values ranged from an average of 3.43 persons per flat (rank 1) to a low of 1.0 person per flat (rank 76). CCDs were ranked from highest value to lowest value.

Residential ratio: The proportion of buildings used for residential purposes to the total number of buildings provides a measure of relative residential land use. Residential buildings were taken to include houses, flats and commercial accommodation (hotels, motels, resorts and caravan parks). Ratios ranged from 99.99% residential to 2.25% residential with a mean of 89.55%. CCDs were again ranked from highest value to lowest value.

Road network density: The road network provides the means for people to move to and from shelter, with the denser the network, the greater the urban mobility. Nodes (i.e road intersections) were extracted from the road network data used in the GIS and the ratio of nodes to road length total number in each CCD was tallied to give a measure of network density. This was chosen as a better measure of network density over road length alone because the ranking of the larger, rural CCDs can be high because of the longer lengths of road involved. Values ranged from a high of 9.7 nodes/km (rank 1) to a low of 1.0 nodes/km (rank 96), with a mean of 5.4 nodes/km.

Cars: Private cars are clearly the most important form of transport (and thus mobility) within Mackay. CCDs were ranked on the estimated number of cars to which households had access. This figure was derived from the figures provided in the 1996 census data for household access to vehicles. Whilst it may not be a completely accurate absolute measure, it is felt to be a good relative measure. Values ranged from 809 to 51 with a mean of 311.8. CCDs were ranked from highest value to lowest value.

Households with no car: This variable has both socio-economic significance and great relevance for emergency managers should evacuations be required. The value used here is the proportion of households within each CCD that do not have access to a car according to the 1996 census. Values ranged from 39.56% of households (rank 1) to zero car-less households (rank 95). The mean for all CCDs was 11.0%.

Suburb-level composite: A composite view of the shelter group variables at the suburb, rather than CCD level, was produced to simplify the analysis of total risk posed by each hazard. This composite was constructed by summing the ranks of each CCD that fell completely or partly within each suburb boundary. That sum was then ranked to produce the map contained as Figure 3.21 and listed in Table 3.10.

Sustenance

Three variables were used to represent the sustenance group of elements at risk.

Logistic facilities: These facilities contribute significantly to the sustainability of the community given that they handle, store or distribute food, fuel and other essential commodities. Their loss or dislocation would significantly limit the viability of the community. The total number of buildings classified as having a logistic or transport and storage function within the Mackay *BUILDING* database were tallied for each CCD. Some 52 CCDs had no such facilities whilst the greatest number was 70. CCDs were ranked from highest value to lowest value.

Lifeline facilities: The proportion of above-ground facilities supporting both power and water supply, such as power sub-stations and water reservoirs, and telecommunications, such as telephone exchanges and broadcast studios, contained in the Mackay *BUILDING* database, have been used to rank CCDs for this utility lifeline variable. Only 21 CCDs contain such facilities, with the greatest number being six in the one CCD. Again, CCDs were ranked from highest value to lowest value.

Lifeline length: Ideally we would have liked to be able to include the lengths of power supply reticulation and water reticulation infrastructure, however, such data were not available for Mackay. As a surrogate we have used the length of road in each CCD. We feel that this is a reasonable surrogate because lifelines such as water supply, sewerage, power supply and telephone cabling are closely related spatially to the road network. The values range from a high of 51.27 km (rank 1) to a low of 1.03 km (rank 96), with a mean of 6.63 km.

Suburb-level composite: A composite view of the shelter group variables at the suburb, rather than CCD level, was produced to simplify the analysis of total risk posed by each hazard. This composite was constructed by summing the ranks of each CCD that fell completely or partly within each suburb boundary. That sum was then ranked to produce the map contained as Figure 3.22 and listed in Table 3.11.

Security

Eight variables were selected to represent the elements at risk that influence community security. In this context security is seen as including health, wealth and the protective services provided. Two of the variables used here have been derived from the SEIFA *Socio-Economic Indexes for Areas* produced by the ABS from the 1996 census. The SEIFA methodology is described in detail in ABS Information Paper 2039.0 (ABS, 1998b).

Public safety: Ambulance, fire, defence force, police and SES facilities, together with hospitals and other medical facilities, provide the bulk of the protective services required by the community. Their loss or dislocation would have a disproportionately large impact on overall public safety. The tally of these buildings in the Mackay *BUILDING* database located in each CCD was used. Only 24 CCDs contained safety facilities, with the greatest number being 24. CCDs were ranked from highest value to lowest value.

Business premises: These facilities make a significant contribution to the overall economy and employment situation, as well as facilitating the distribution of goods and services. Again, the tally of buildings classified as having a business or industrial function, in the Mackay BUILDING database, contained in each CCD was used. In all, 69 CCDs contained such buildings, with the greatest number being 140. Again, CCDs were ranked from highest value to lowest value.

Relative Socio-Economic Disadvantage: The SEIFA *Index of Socio-Economic Disadvantage* (ABS, 1998b) has been compiled by the ABS by undertaking a principal components analysis on 20 weighted variables from the 1996 census. The attributes, such as low income, low educational attainment, high unemployment and jobs in relatively unskilled occupations, were selected to highlight disadvantage (see Table C1). The resulting index has been standardised to have a mean of 1000 and a standard deviation of 100 across all CCDs in Australia. This means that around 95% of index scores across Australia are between 800 and 1200. A value above 1200 reflects a significantly high degree of advantage, whilst a value of less than 800 reflects a significantly high level of disadvantage.

For Mackay, the socio-economic disadvantage index ranges from a low of 702.39, three standard deviations below the national mean, whilst the highest index is 1078.34. The study area mean is 967.70. CCDs were ranked from lowest value (most disadvantaged) to highest (least disadvantaged).

Economic Resources: SEIFA also provides an *Index of Economic Resources* (ABS, 1998b). This index is based on a profile of the economic resources of families. It is compiled from 22 weighted variables that reflect the income and expenditure of families, including measures of income, rent and home ownership (see Table C2). This index is also standardised with a national mean of 1000 and a standard deviation of 100. For Mackay CCDs, values range from a low of 787.51 to a high of 1112.25. Again CCDs were ranked from lowest to highest value.

People under five years of age: The very young are felt to be less resilient in the face of disaster impacts than older children and adults. For this attribute, we have taken the proportion of the total CCD population at the 1996 census that was under five years of age. Percentages range from a high of 15.61% (rank 1) to a low of 2.51% (rank 96) with a mean of 7.72%.

People over 65 years of age: The vulnerability of the elderly to disaster impact is similar to that of the very young. Here we have taken the proportion of the total CCD population at the 1996 census that was over 65 years of age. Percentages range from a high of 30.24% (rank 1) to a low of 1.59% (rank 96) with a mean of 10.90%.

Households renting: The proportion of households that were renting their accommodation is also seen as an indicator of economic resilience. Percentages calculated from the 1996 census data range from 64.62% (rank 1) to a low of 6.82% (rank 96).

Unemployment: A widely used indicator of economic vulnerability is the rate of unemployment. The rate for each CCD included in the 1996 census data was used here because of its availability and consistency with other measures. We have assumed that whilst the actual rates of unemployment may have changed since 1996, the relative distribution probably has not. Values range from a high of 49.23% (rank 1) to a low of 3.55% (rank 96).

Suburb-level composite: A composite view of the shelter group variables at the suburb, rather than CCD level, was produced to simplify the analysis of total risk posed by each hazard. This composite was constructed by summing the ranks of each CCD that fell completely or partly within each suburb boundary. That sum was then ranked to produce the map contained as Figure 3.23 and listed in Table 3.12.

Society

Seven variables were used to reflect the social elements at risk.

Community facilities: A wide range of practical, social and cultural services supports the community. These range from schools, churches and libraries, to sporting and social clubs, and from public toilets to government offices. The number of such buildings, in the Mackay *BUILDING* database, contained in each CCD was tallied. In all, 69 CCDs contained community buildings with the greatest number being 35 (rank 1).

Large families: In a disaster situation, especially where evacuations are involved, larger families are frequently at a disadvantage. In this context ‘large’ families were taken to be those with three or more children or other dependants living at home. The percentage of such families of the total number of families in each CCD was calculated from the 1996 census data. Values ranged from 25.70% (rank 1) to no large families in one CCD (rank 96). The community mean was 15.51%.

Single parent families: Single parent families, especially those who are ‘women-led’, are also felt to be particularly vulnerable, both socially and economically. The 1996 census data does not permit women-led single parent families to be separately identified from the total, though it seems safe to assume that the majority of such families will have a female as the sole adult. The percentage of all families which have only a single parent was calculated with the highest (rank 1) being 36.92%, whilst a single CCD had no single parent families (rank 96). The community mean was 15.47%.

Visitors: Visitors are considered to have a greater inherent level of vulnerability than do residents because of their lack of familiarity with the local environment and their relative isolation from the general community. In many tourist destinations they are also the group that has the greatest concentration of non-English speakers, though we have no clear data for international tourists for Mackay. The percentage of visitors (both overseas and domestic) in the total CCD population in the 1996 census was used. The highest percentage of visitors was 32.68% (rank 1). Only one CCD had no visitors. The overall mean was 7.03% .

Education and Occupation: The third SEIFA index included in this study is the *Index of Education and Occupation* (ABS, 1998b). This index is based on an analysis of 18 weighted variables selected to reflect the educational and occupation structures of communities (see Table C5). High scores reflect communities with high concentrations of people with higher education or undergoing further education and with people employed in higher skilled occupations; conversely low index values indicate low educational levels and largely unskilled employment categories. Values range from 754.38 (rank 1) to a high of 1054.09 (rank 96) with a community mean of 943.61.

New residents: People who have lived at their census address for less than five years have been included because they can indicate vulnerability through a lack of awareness of the local disaster environment and lack of strong community links. These 'new residents' include longer-term residents who have simply moved residence within the area, though the great majority have moved from other statistical local areas (SLA). CCDs were ranked on the proportion of people over five years of age that were living at a different address to that at the 1991 census to the total CCD population over five years. Values range from 85.26% (rank 1) to a low of 25.94% (rank 96). The community mean was 47.42%.

No religious adherence: Lack of strong social links, such as adherence to a religion, is seen as an indicator of susceptibility. CCDs were ranked on the proportion of the total population who indicated in their response to the 1996 census that that they had 'no religion'. Percentages range from a high of 25.5% (rank 1) to a low of 5.63% (rank 96) and a mean of 13.79%.

Suburb-level composite: A composite view of the societal group variables at the suburb, rather than CCD level, was produced to simplify the analysis of total risk posed by each hazard. This composite was constructed by summing the ranks of each CCD that fell completely or partly within each suburb boundary. That sum was then ranked to produce the map contained as Figure 3.24 and listed in Table 3.13.

Composite Ranking

To provide a composite rating of the **relative contribution of each suburb to overall community vulnerability**, the ranks for the 30 variables for each CCD that fell completely or partly within each suburb boundary were summed and that sum ranked. The resulting values were used to produce Figure 3.25 and Table 3.14.

Further Development

It is clear that this methodology is still at an early stage of its development and that it requires further work. We have already identified a number of aspects that demand further research and development to be addressed in a separate research project to be undertaken by external consultants. We would also welcome any suggestions, comments and/or advice, that readers may have to improve it.

Weighting: No attempt has been made to weight the individual variables within each group. Our research has not reached the stage where we can confidently judge the relative significance of, for example, houses, as opposed to flats, as opposed to the road network, in the shelter group; nor can we yet judge the relative contribution of each group to the overall evaluation.

There is, none-the-less, a weight inferred by simply including the attribute in the assessment.

The method used in this study for reaching the composite vulnerability profile values is a departure from the method used for the Cairns study (see Appendix E in Granger and others, 1999). In that study, we multiplied the ranks for each of the 'five esses' to achieve the composite community value. In our ongoing review and development of this methodology we have recognised that the approach used for the Cairns study implicitly weights each individual variable depending on the number of variables contained in each group. 'Total Population', for example, because it was the sole variable used in the setting group for Cairns, carried a significantly greater weight than did say 'Logistic Facilities' which was one of eight variables in the security group. In the methodology employed in this study the ranks for each of the 30 variables were summed to achieve an overall community vulnerability profile rank. A comparison of the outcomes of applying the 'Cairns method' and the method used in this study is made with Figure D.1 and Figure D.2. The actual ranks produced by the two methods are listed in Table D.1.

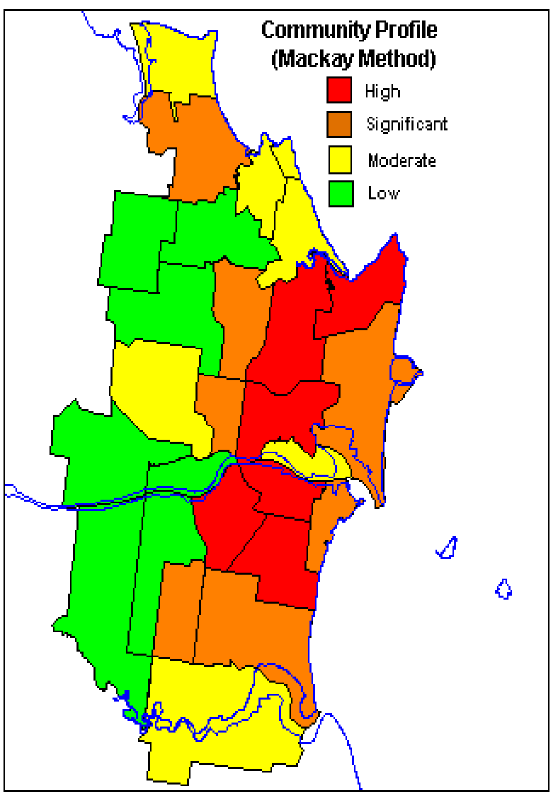

Figure D.1: Total risk ranks using 'Mackay' method

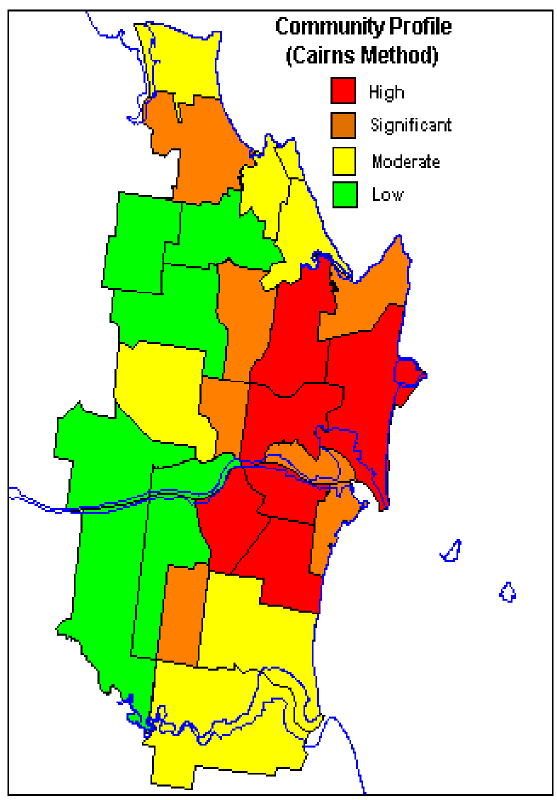

Figure D.2: Total risk ranks using 'Cairns' method

Table D.1: Comparison of total risk ranks using 'Mackay' and 'Cairns' methods

SUBURB	MACKAY	CAIRNS	SUBURB	MACKAY	CAIRNS
Andergrove	3	3	Mount Pleasant	11	9
Bakers Creek	16	18	Nindaroo	23	25
Beaconsfield	10	11	North Mackay	4	5
Blacks Beach	19	17	Ooralea	12	12
Bucasia	8	10	Paget	13	14
Central Mackay	2	1	Racecourse	25	24
Cremorne	18	13	Richmond	22	23
Dolphin Heads	20	19	Rural View	21	21
East Mackay	7	7	Shoal Point	17	20
Eimeo	15	16	Slade Point	6	8
Erakala	26	26	South Mackay	1	2
Foulden	27	27	Te Kowai	24	22
Glenella	14	15	West Mackay	5	4
Mackay Harbour	9	6			

The most significant difference is in the results for Cremorne which is five ranks higher using the 'Cairns' method. All other results are within three ranks. We believe, however, that the 'Mackay' method is likely to prove to be preferable to the 'Cairns' method because of the latter's implicit, if unintended, weighting.

Facility importance: By contrast, the importance of individual facilities such as the airport, hospitals, rail terminal, port and police headquarters to overall community vulnerability are probably under-stated because they are simply dealt with as one of a number of buildings. This is particularly an issue for those facilities, such as the airport and police stations, that have only limited distribution, but service a wider area. Further research is needed to incorporate their catchment suburbs in addition to the suburbs in which they actually are located. Established geographic techniques, including distance decay and nearest neighbour analysis, are likely to hold potential.

A similar problem arises with buildings that have dual or multiple functions - should they be counted in more than one attribute? For example, the control tower at the airport has only been counted as a logistic support facility. However, in addition to its role in the operation of the airport, it is also a major aeronautical telecommunications hub - equivalent in many ways to the regional telephone exchange. It was not, however, counted in the telecommunications attribute.

Further consideration is also needed to take account of the functional significance of facilities and the degree to which the functions they provide can be taken up by other facilities in the event of loss or isolation. Functional significance can be measured in terms of the extent of the impact of a facility being lost. A local 'corner store', for example, has a relatively localised catchment and people who rely on it can typically find an alternate source of the same services in an adjacent neighbourhood or at a higher order facility such as the suburban supermarket or regional shopping plaza. It has a low order of functional significance and a high degree of redundancy. The bulk sugar loading facilities in the port, by contrast, have at least national significance, given their role in the shipping of a major export commodity. The loss of those facilities would cause a significant dislocation to the local, state and national economies, especially if an alternate port (e.g. the closest being Townsville to the north or Bundaberg to the south) did not have the capacity to easily handle the extra demand. The sugar facilities have a high order of functional significance and a low degree of redundancy.

Whilst there is clearly scope for further research and refinement, we feel that it is appropriate, given the community-level focus of this study, to ignore the functional significance and redundancy issue in terms of weighting the facilities in the community vulnerability profile. The focus is on the risk to the community under study. For risk assessments covering broader and more complex regions (e.g. South-East Queensland), or for communities that host a concentration of high order facilities (e.g. Gladstone) such issues will, however, need to be addressed.

Facilities versus buildings: In the analysis undertaken here, the total number of buildings in a given category has been used rather than the number of facilities. This has probably produced a bias where a facility is made up of a large number of individual buildings. That facility makes a greater contribution than an equivalent facility that consisted of a single large building. This is most notably the case with nursing homes and schools. A sensitivity analysis needs to be conducted on this aspect.

Conclusion

Regardless of the obvious limitations in the methodology employed here to provide a measure of the relative contribution each suburb makes to overall community vulnerability, we do not believe they invalidate it, or the assessment it has produced. Whilst it is hardly a scientific test, the assessment fits our intuitive assessment fairly well - it contains no surprises. Its application in other centres, including Gladstone, South-East Queensland, Newcastle and Sydney, will undoubtedly produce further refinements.

This is another step on what will hopefully continue to be a fruitful journey.

APPENDIX E: MODIFIED MERCALLI (MM) SCALE OF EARTHQUAKE INTENSITY (after Dowrick, 1996)

MM I *People*
Not felt except by a very few people under exceptionally favourable circumstances.

MM II *People*
Felt by persons at rest, on upper floors or favourably placed.

MM III *People*
Felt indoors; hanging objects may swing, vibrations may be similar to passing of light trucks, duration may be estimated, may not be recognised as an earthquake.

MM IV *People*
Generally noticed indoors but not outside. Light sleepers may be awakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building.

Fittings
Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock.

Structures
Walls and frame of building are heard to creak, and partitions and suspended ceilings in commercial buildings may be heard to creak.

MM V *People*
Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people alarmed.

Fittings
Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Hanging pictures knock against the wall. Open doors may swing. Cupboard doors secured by magnetic catches may open. Pendulum clocks stop, start, or change rate.

Structures
Some windows Type I cracked. A few earthenware toilet fixtures cracked.

MM VI *People*
Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily.

Fittings
Objects fall from shelves. Pictures fall from walls. Some furniture moved on smooth floors, some unsecured free-standing fireplaces moved. Glassware and crockery broken. Very unstable furniture overturned. Small church and school bells ring. Appliances move on bench or table tops. Filing cabinets or “easy glide” drawers may open (or shut).

Structures
Slight damage to Buildings Type I. Some stucco or cement plaster falls. Windows Type I broken. Damage to a few weak domestic chimneys, some may fall.

Environment
Trees and bushes shake, or are heard to rustle. Loose material may be dislodged from sloping ground, e.g. existing slides, talus slopes, shingle slides.

MM VII *People*
General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars who may stop.

Fittings
Large bells ring. Furniture moves on smooth floors, may move on carpeted floors. Substantial damage to fragile contents of buildings.

Structures
Unreinforced stone and brick walls cracked. Buildings Type I cracked with some minor masonry falls. A few instances of damage to Buildings Type II. Unbraced parapets, unbraced brick gables, and architectural ornaments fall. Roofing tiles, especially ridge tiles, may be dislodged. Many unreinforced chimneys damaged, often falling from roof-line. Water tanks Type I burst. A few instances of damage to brick veneers and plaster or cement-based linings. Unrestrained water cylinders (Water Tanks Type II) may move and leak. Some windows Type II cracked. Suspended ceilings damaged.

Environment
Water made turbid by stirred up mud. Small slides such as falls of sand and gravel banks, and small rock-falls from steep slopes and cuttings. Instances of settlement of unconsolidated or wet, or weak soils. Some fine cracks appear in sloping ground. A few instances of liquefaction (i.e. small water and sand ejections).

MM VIII *People*
Alarm may approach panic. Steering of motor cars greatly affected.

Structures
Buildings Type I, heavily damaged, some collapse. Buildings Type II damaged, some with partial collapse. Buildings Type III damaged in some cases. A few instances of damage to Structures Type IV. Monuments and pre-1976 elevated tanks and factory stacks twisted or brought down. Some pre-1965 infill masonry panels damaged. A few post-1980 brick veneers damaged. Decayed timber piles of houses damaged. Houses not secured to foundation may move. Most unreinforced domestic chimneys damaged, some below roof-line, many brought down.

Environment
Cracks appear on steep slopes and in wet ground. Small to moderate slides in roadside cuttings and unsupported excavations. Small water and sand ejections and localised lateral spreading adjacent to streams, canals, lakes, etc.

MM IX *Structures*

Many buildings Type I destroyed. Buildings Type II heavily damaged, some collapse. Buildings Type III damaged, some with partial collapse. Structures Type IV damaged in some cases, some with flexible frames seriously damaged. Damage or permanent distortion to some Structures Type V. Houses not secured to foundations shifted off. Brick veneers fall and expose frames.

Environment
Cracking of the ground conspicuous. Landsliding general on steep slopes. Liquefaction effects intensified and more widespread, with large lateral spreading and flow sliding adjacent to streams, canals, lakes, etc.

MM X *Structures*
Most Buildings Type I destroyed. Many Buildings Type II destroyed. Buildings Type III heavily damaged, some collapse. Structures Type IV damaged, some with partial collapse. Structures Type V moderately damaged, but few partial collapses. A few instances of damage to Structures Type VI. Some well-built timber buildings moderately damaged (excluding damage from falling chimneys). Dams, dykes, and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves.

Environment
Landsliding very widespread in susceptible terrain, with very large rock masses displaced on steep slopes. Landslide dams may be formed. Liquefaction effects widespread and severe.

MM XI *Structures*
Most Buildings Type II destroyed. Many Buildings Type III destroyed. Structures Type IV heavily damaged, some collapse. Structures Type V damaged, some with partial collapse. Structures Type VI suffer minor damage, a few moderately damaged.

MM XII *Structures*
Most Buildings Type III destroyed. Many Structures Type IV destroyed. Structures Type V heavily damaged, some with partial collapse. Structures Type VI moderately damaged.

Construction types

Buildings Type I Buildings with low standard of workmanship, poor mortar, or constructed of weak materials like mud brick or rammed earth. Soft storey structures (e.g. shops) made of masonry, weak reinforced concrete, or composite materials (e.g. some walls timber, some brick) not well tied together. Masonry buildings otherwise conforming to Buildings Type I–III, but also having heavy unreinforced masonry towers. (Buildings constructed entirely of timber must be of extremely low quality to be Type I).

Buildings Type II Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces. Such buildings not having heavy unreinforced masonry towers.

Buildings Type III Reinforced masonry or concrete buildings of good workmanship and with sound mortar, but not formally designed in detail to resist earthquake forces.

Structures Type IV Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special collapse or damage limiting measures taken (mid 1930s to c. 1970 for concrete and to c. 1980 for other materials).

Structures Type V Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special damage limiting measures taken, other than code requirements, dating from since c. 1970 for concrete and c. 1980 for other materials.

Structures Type VI Structures dating from c. 1980 with well defined foundation behaviour, which have been especially designed for minimal damage, e.g. seismically isolated emergency facilities, some structures with dangerous or high (value) contents, or new generation low damage structures.

Windows
Type I – Large display windows, especially shop windows.
Type II – Ordinary sash or casement windows.

Water tanks
Type I – External, stand mounted, corrugated iron water tanks.
Type II – domestic hot-water cylinders unrestrained except by supply and delivery pipes.

APPENDIX F: EARTHQUAKES IN THE MACKAY REGION

AGSO World Earthquake Database and QUAKES Database (University of Queensland) 21-Mar-2000

Date: 01 January 1840 to 21 March 2000
Latitude: 19°S to 24°S
Longitude: 146.5°E to 152.5°E
Depth: 0 km to 100 km
Magnitude: greater than 2

Table F.1: Earthquakes in the Mackay region

Source	Date	Time	Lat	Long	Depth	Local magnitude	Authority
QUNI	18751111	105000	-22.000	148.5	30	4.5	QUNI
QUNI	19000509	0	-19.300	146.8	0	2.2	QUNI
RYNN	19121206	170000	-23.900	151.2		3.5	E/M
QUNI	19131218	135400	-20.000	147.0	33	5.7	RYNN
QUNI	19180606	181500	-23.500	152.5	10	5.1	QUNI
QUNI	19180606	181424	-23.500	152.5	15	6.3	QUNI
RYNN	19180606	182300	-23.500	152.5	0	5.5	RYNN
QUNI	19180606	190000	-23.500	152.5	10	5.1	QUNI
RYNN	19180606	192000	-23.500	152.5	0	5.7	RYNN
QUNI	19180606	194500	-23.500	152.5	10	5.1	QUNI
QUNI	19180606	201500	-23.500	152.5	10	5.1	QUNI
QUNI	19220307	165450	-23.500	152.5	10	4.5	QUNI
JONES	19500405	195052	-21.100	149.2	33	4.5	ISO
QUNI	19591125	43102.6	-19.700	147.7	0	3.3	QUNI
QUNI	19601019	113706.3	-21.200	149.5	5	4.5	QUNI
QUNI	19601019	121204	-21.300	149.4	5	2.8	QUNI
QUNI	19621228	125022.6	-19.300	148.0	10	2.4	QUNI
QUNI	19630212	160251.2	-20.250	146.6	10	3.0	QUNI
QUNI	19670318	203922	-19.000	148.4	10	2.5	QUNI
QUNI	19690111	210517	-20.900	148.0	10	2.4	E/M
RYNN	19720505	133250	-19.000	146.5		3.0	E/M
RYNN	19780524	173759.5	-20.600	146.7	10	4.0	CTA
AUST	19781128	184455.5	-23.370	152.46	31	4.5	BRS
QUNI	19800208	44207.3	-21.794	150.537	9	4.3	ML
QUNI	19810913	155824.6	-19.184	149.235	9	2.1	ML
QUNI	19811021	202156	-19.577	148.828	5	2.1	ML
QUNI	19811113	191942	-21.442	148.107	6	2.3	ML
RYNN	19820615	132124.7	-19.302	150.52	0	2.7	MD
RYNN	19821116	153421.4	-19.581	148.615	2	2.3	MD
RYNN	19821231	91945.5	-20.464	147.262	0	2.1	MD
GSQLD	19831113	64212.2	-21.035	146.799	5	4.5	MD
GSQLD	19840419	65018	-21.764	146.512	13	2.8	GSQL
QUNI	19850607	221335.3	-20.200	149.033	4	2.3	QUNI
AUST	19850727	164346.7	-19.281	148.48	5	3.5	AUST
GSQLD	19850802	121658.4	-19.443	149.203	10	4.7	GSQL
AUST	19870927	160126.3	-19.304	147.825	9	4.6	AUST
QUNI	19880226	134619.2	-19.210	149.071	4	3.3	QUNI
AUST	19880521	22319.8	-23.700	151.69	9	3.4	AUST

QUNI	19890210	150906.7	-23.784	151.947	10	2.4	QUNI
QUNI	19890326	141843.7	-21.390	151.205	19	2.4	QUNI
QUNI	19891119	120046.1	-19.358	148.763	10	2.9	QUNI
QUNI	19891119	123750	-19.790	148.99	4	2.9	QUNI
QUNI	19900312	11729.6	-20.142	150.923	5	3.0	QUNI
QUNI	19900609	40610.3	-23.364	147.822	19	2.9	QUNI
QUNI	19901103	194907.1	-23.402	149.16	8	2.7	QUNI
QUNI	19901211	161029.6	-23.610	150.619	6	2.3	QUNI
QUNI	19910315	42900.6	-23.816	152.378	8	2.4	QUNI
QUNI	19910406	14445.4	-20.499	149.814	8	3.2	QUNI
QUNI	19910413	32829	-20.429	150.264	8	2.7	QUNI
QUNI	19910610	120023.2	-23.609	150.658	0	2.9	QUNI
QUNI	19910610	130044	-23.607	150.644	10	2.9	QUNI
QUNI	19910911	53608.4	-19.712	148.895	9	3.2	QUNI
QUNI	19910911	71337	-19.792	148.979	11	3.0	QUNI
QUNI	19911112	40842	-22.605	152.263	8	2.2	QUNI
QUNI	19911214	134612	-22.378	151.833	8	2.6	QUNI
QUNI	19920521	14515.4	-21.087	147.93	3	2.2	QUNI
QUNI	19920730	82351.9	-19.444	149.609	5	3.1	QUNI
QUNI	19920804	95353.6	-21.429	151.716	8	2.6	QUNI
QUNI	19930223	211236.1	-19.755	149.773	8	2.6	QUNI
QUNI	19940617	115233.8	-20.208	148.867	4	3.4	QUNI
QUNI	19950827	20700	-20.625	147.121	0	2.3	QUNI
QUNI	19951030	171842.2	-19.487	147.426	10	2.4	QUNI
QUNI	19961005	34104.7	-23.177	151.547	10	2.8	QUNI
QUNI	19970215	132850.6	-20.400	146.553	10	3.5	QUNI
QUNI	19971024	183112.6	-20.400	147.098	19	2.6	QUNI
AUST	19981102	170938.1	-22.808	151.146	0	4.7	AUST
ASC	19990325	122608.8	-20.359	146.755	0	3.4	ASC
ASC	19990424	214848.7	-20.159	146.966	0	2.7	ASC

Source

ASC	AGSO Seismological Centre
AUST	AGSO Seismological Centre
GSQLD	Geological Survey of Queensland
JONES	Jones, 1959 (see References)
QUNI	University of Queensland
RYNN	Rynn, 1987 (see References)

Authority for magnitude

ASC	AGSO Seismological Centre
AUST	AGSO Seismological Centre
BRS	Brisbane seismograph
CTA	Charters Towers seismograph
E/M	Estimated magnitude
GSQL	Geological Survey of Queensland
GSQLD	Geological Survey of Queensland
ISO	Isoseismal map

JONES	Jones, 1959 (see References)
MD	Duration magnitude
ML	Local (Richter) magnitude
QUNI	University of Queensland
RYNN	Rynn, 1987 (see References)

APPENDIX G: PREPARATION OF MAP OF NATURAL PERIOD, EARTHQUAKE HAZARD MAP, AND EARTHQUAKE SHAKING SCENARIOS FOR MACKAY

This appendix contains three Parts:

- **PART A**: Preparation of Mackay map of natural period
- **PART B**: Preparation of Mackay earthquake hazard map
- **PART C**: Generation of earthquake shaking scenarios for Mackay.

PART A: Preparation of map of natural period for Mackay

The map of natural period for Mackay (Figure 4.4) shows point values and contours of measured natural period *T* of the ground, in the period range of interest with regard to structures *T* = 0.07 s to *T* = 2.0 s.

NOTE: <u>Limitations of the earthquake hazard maps</u>

The maps indicate the earthquake ground shaking hazard at a generalised local level. They should not be considered accurate at a site-specific level and should not be used to replace site investigations where required by building codes or local regulations.

Method used

The single site, H/V, or 'Nakamura' method was used. In this method the horizontal, spectral, ground shaking is divided by the vertical, spectral, ground shaking to produce H/V spectral ratio plots. A resonant peak may be observed in the spectral ratio plot for a site, and that peak is interpreted to occur at the fundamental period of vibration of the sediment column. A large body of theoretical and empirical research from the past decade has analysed the H/V method and compared its prediction of the fundamental ground period with, for example, assessments made from earthquake recordings (e.g., Nakamura, 1989; Lachet and Bard, 1994; Field and Jacob, 1995; Nakamura, 2000). The results generally indicate that the method is robust in revealing the natural period of sediment vibration excited by vertically incident seismic shear waves.

We recorded very weak, ambient, ground vibrations, or 'microtremors', created by wind, surf action, traffic, etc., with portable seismographs to reveal resonances in the sediments. *In situ* recordings of local earthquake shaking are the best method to determine the response of sediments but none is available in Mackay and are not likely to be for a significant time, even were instruments to be installed (there are no monitoring instruments in Mackay).

Field recording

AGSO seismologists used portable, digital seismographs to record microtremors at about 230 sites in Mackay in 1997 (Figure 4.4). Sensors were triaxial, passive type with a natural period of 1 s, and sampling rate was 100 Hz. The sites had a nominal 500 m spacing and were located primarily on sediments. Two recordings, each of 200 s duration, were made at each site.

Data processing

The recordings were divided into time series of 40 s duration each with 1 s overlap and the Fourier spectra of these were averaged. Median horizontal spectra divided by median vertical spectra, with attendant ±σ deviations, were used to produce the spectral ratio plots. The FFT computer programs written by Cvetan Sinadinovski and other programs written by Vic Dent and Long Cao, all of AGSO, were used to process the data.

Resonant period *T*, where observed, was interpreted for each microtremor site. Point values of *T* are shown on the map of natural period (Figure 4.4). These values were contoured using ArcInfo V7.2.1 *tincontour* programs to produce the final contour map.

Quality factors (of microtremor resonance) were assigned to the sites as follows:

- Quality A - pronounced, narrow, resonant peak observed in the spectral ratio plot;
- Quality B - broader-based resonant peak observed; the resonant period is more difficult to assess accurately than for Quality A sites;
- Quality C - resonance not observed or resonance not reliably observed. Sites where resonance was not observed appear on the map with a nominal period *T* = 0.1 s.

PART B: Preparation of Mackay earthquake hazard map

The Mackay earthquake hazard map is shown in Figure 4.2.

NOTE: Limitations of the earthquake hazard maps

The maps indicate the earthquake ground shaking hazard at a generalised local level. They should not be considered accurate at a site-specific level and should not be used to replace site investigations where required by building codes or local regulations.

We used a two-stage method to prepare the Mackay earthquake hazard map. The stages are:

- Stage 1 **- Subdivide the city into zones of differing earthquake hazard according to defined site classes**
- **Stage 2** - Assign amplification factors to the site classes and hence to the zones of differing earthquake hazard.

Stage 1 - Subdivide the city into zones of different earthquake hazard according to defined site classes

Our site classifications are based on those published in the 1997 Provisions of the US National Earthquake Hazards Reduction Program (NEHRP), published by the US Building Seismic Safety Council (1997). Their site classes are described in Table G.1 and we have included extra lithological descriptions in the table from Crouse and McGuire (1996) and Hwang and others (1997).

We used the preliminary 1:100 000 scale geological map of Mackay (Figure 2.3; von Gnielinski, in preparation), a large database of groundwater borehole logs provided by Queensland Department of Natural Resources, geotechnical information provided by Queensland Rail, and the outputs of AGSO's Mackay microtremor survey to determine the earthquake hazard zones defined by site class.

All areas of rock outcrop in Mackay were included in the earthquake hazard map as Site Class B. Seismic shear wave velocities in some Mesozoic and older geological units may in fact be greater than 1500 ms^{-1} and, if so, the accurate classification of these units would be Site Class A, but we have no information to distinguish between Site Class A and Site Class B. No direct measurements of shear wave velocities were available for Mackay, as is commonly the case for Australian cities.

We classified small areas of Mackay as Site Class C. These are areas of Tertiary/Quaternary colluvium comprising material transported, largely by gravity, from the adjacent Carmila Beds in suburbs Nindaroo and Habana (see the Mackay geological map, Figure 2.3).

The rest of onshore Mackay we have classified as Site Class D (stiff clays, medium dense to dense sands), including areas where landfill has been placed over sediments (Table G.1).

To arrive at the Site Class D classification, we estimated mean seismic shear wave velocity to a depth of 30 m below the earth's surface (Vs). Shear wave velocity in the top 30 m is the key determinant for site class (Table G.1).

Table G.1: Site classes for earthquake hazard maps (based on Building Seismic Safety Council, 1997)

Site Class	Site Class definition
A	**HARD ROCK** Vs > 1500 ms^{-1}
B	**ROCK** 760 ms^{-1} < Vs ≤ 1500 ms^{-1}
C	**VERY DENSE SEDIMENTS AND SOFT ROCK** Hard and/or very stiff sediments, very dense soils, mostly gravels, and soft rock with 360 ms^{-1} < Vs ≤ 760 ms^{-1} or with either N > 50 or s_u ≥100 kPa
D	**STIFF SEDIMENTS** Sands, silts and/or stiff clays, some gravels, with 180 ms^{-1} ≤ Vs ≤ 360 ms^{-1} or with either 15 ≤ N ≤ 50 or 50 kPa ≤ s_u ≤100 kPa
E	**SOFT SEDIMENTS** A sediment profile with Vs < 180 ms^{-1} or with either N < 15 or s_u < 50 kPa or any profile with more than 3 m of soft clay defined as sediment with PI > 20, w ≥ 40%, and s_u <25 kPa
F	**SEDIMENTS REQUIRING SITE-SPECIFIC EVALUATION** • sediments vulnerable to potential failure or collapse under seismic

	loading such as liquefiable sediments, quick and highly sensitive clays, collapsible weakly-cemented sediments • peats and/or highly organic clays (thickness > 3 m) • very high plasticity clays (thickness > 8 m with PI > 75) • very thick soft/medium stiff clays (thickness > 36 m)

NOTES:
Vs = Mean shear wave velocity to a depth of 30 m
N = Mean Standard Penetration Test blow count to a depth of 30 m
s_u = Mean Undrained Shear Strength to a depth of 30 m
PI = Plasticity Index
w = Moisture content

The natural period of ground vibration, *T*, measured in the microtremor survey and the thickness of Mackay sediments, *H*, determined from the DNR borehole database, yields estimates of Vs. Where 'soft' sediments overlie 'hard' rock, resonant vibration in the sediments occurs for shear waves with a wavelength of four times the sediment thickness. In that case:

$$Vs = \frac{4H}{T}$$

where *Vs* is seismic shear wave velocity in metres per second, *T* is resonant period of the fundamental mode of vibration in seconds and *H* is sediment thickness in metres. We assume:

- **the interface between the sediments and the underlying bedrock is subhorizontal and planar. This is not true at a site-specific scale and many channels are cut into the bedrock (Linda Foster, verbal communication, 1999). However, our assumption is reasonable on a more general scale demonstrated by the remarkable consistency of natural period values across large areas of Mackay;**
- **we are observing the fundamental period of ground vibration in the spectral ratio plots;**
- **the microtremor technique is sampling the sediment column and not the bedrock below. This will be so if there is a significant contrast in seismic impedance between sediments and bedrock. In Mackay this is the case except perhaps where bedrock is highly weathered to significant thicknesses. Weathered bedrock in Mackay may be several metres thick (up to about 20 m but generally about 0 - 10 m from DNR borehole records).**

We abstracted Quality A and B microtremor sites within about 500 m of boreholes listed in the DNR database and formed a set of pairs of microtremor sites and nearest borehole. The site pairs are located on all of the main Quaternary geological units found in Mackay. Most of the pairs are located south of the Pioneer River on undifferentiated Quaternary sediments (unit Qa). Site pairs are also located north of the Pioneer, sampling three other sediment units: Qhe, Qpb and Qhb. Our results cannot distinguish differences in seismic velocities among the different geological units. The mean distance between the 17 Quality A microtremor sites and their respective paired borehole was 326 m with a standard deviation of 133 m.

Seismic shear wave velocities Vs in sediments in Mackay of thicknesses from about 12 metres to 30 metres lie in the range 180 ms^{-1} to about 340 ms^{-1} (Figure G.1). Figure G.1 indicates that these velocities are in the upper ranges where sediments are thicker, and that velocities in the lower ranges where sediments are thinner, as may be expected if consolidation has occurred that is related to thickness of overburden. Sparse microtremor Quality B data suggest that shear wave velocities may be between 100 ms^{-1} and 200 ms^{-1} in sediments less than about 10 m thick.

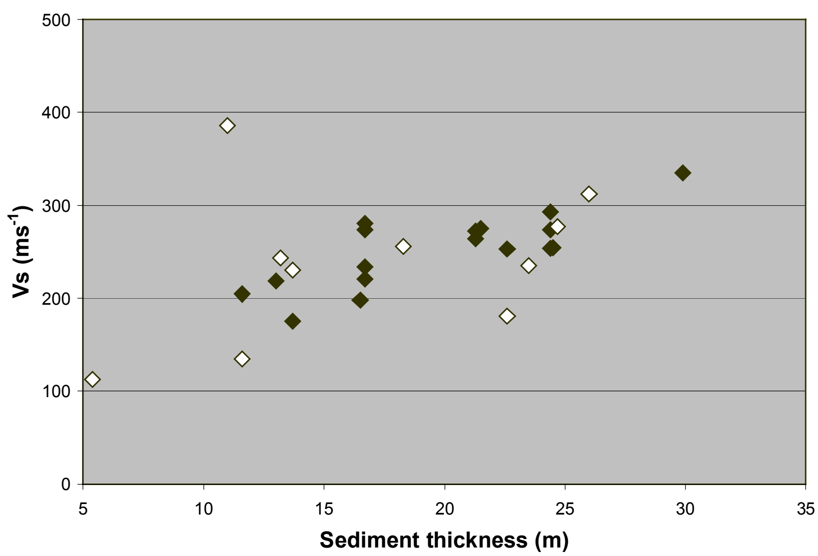

Figure G.1: Relationship between seismic shear wave velocity (Vs) and sediment thickness in Mackay. Dark symbols indicate Quality A microtremor sites, light symbols indicate Quality B microtremor sites.

These seismic shear wave velocities in the Mackay sediments alone place them clearly in Site Class D (Table G.1). However, our method classifies the mean shear wave velocity in the top 30 m of the ground and so bedrock shear wave velocities must be taken into account where sediments are less than 30 m thick. For reasonable values of bedrock shear wave velocities, areas in Mackay where sediment are thicker than about 10 - 15 m clearly match the Site Class D velocity criteria. Where sediments are thinner than 10 m mean shear wave velocities in the top 30 m could be more than 360 ms^{-1} and the resultant site class is Site Class C. In the absence of shear wave velocity measurements in rocks found in Mackay, we have taken the conservative action of classifying all areas in Mackay underlain by Quaternary sediments as Site Class D. The borehole depths to bedrock (Figure 4.3) indicate where sediments may be less than 10 m thick.

Table G.2: Relationship between site class and geological unit for Mackay

Site class	Geological unit[1]	Lithological Description
B	D-Cc, Pc, Kgw, Kgp, Kgo, Kgd	Extensive rock outcrop in northern suburbs of Devonian-Carboniferous Campwyn beds, Permian Carmila Beds, Cretaceous diorites, granodiorites and dolerites

C	TQc	Small areas of Pleistocene-Holocene colluvium
D	Qa, Qa1, Qhe, Qhb, Qhd[2], Qpb, F	Widespread areas of Quaternary floodplain alluvium, Holocene estuarine sediments, Holocene and Pleistocene beach sand deposits south of Pioneer River and in coastal northern suburbs. Areas of landfill over sediments

NOTES:
[1] von Gnielinski, in preparation
[2] Parts of Qhd in Shoal Point are zoned Site Class C

In this study we did not find evidence of clays that would indicate Site Class E and we did not search specifically for geological conditions that would indicate special sites (Site Class F in Table G.1).

Stage 2 - Assign amplification factors to the site classes

The amplification factors describe the relative severity of earthquake shaking. The amplification factor for Site Class B, 'rock', is unity and the severity of ground shaking on other site classes is expected to vary in proportion to the amplification factors. The amplification factors are period-dependent and intensity-dependent. Note that spectral values are used. These describe the motion of an idealised oscillator relative to its 'foundations', which are themselves moving due to earthquake ground motion.

In the absence of sufficient recordings of Australian earthquakes, our amplification factors are taken from the US NEHRP provisions (Building Seismic Safety Council, 1997). Table 4.5, reproduced from Chapter 4, presents the amplification factors for short period vibration (T = 0.3 s) and medium period vibration (T =1.0 s in the NEHRP Provisions, $T \geq 0.7$ s for the Australian response spectra described in Part C of this appendix).

The short-period amplification factors are comparable with but not identical to those in *AS1170.4-1993*. The short-period amplification factors will match closely those in the revision of *AS1170.4-1993* for the lowest level of ground shaking in Table 4.5. Table 4.5 additionally contains amplification factors for stronger shaking that will not be included in the revision of *AS1170.4-1993*.

Table 4.5: Amplification factors for site classes (modified from Building Seismic Safety Council, 1997)

Site Class B Spectral Acceleration	Site Class				
	A	**B**	**C**	**D**	**E**
Short-Period (T=0.3 s) (g)	**Short-period Amplification Factor**				
≤ 0.25	0.8	1.0	1.2	1.6	2.5
0.50	0.8	1.0	1.2	1.4	1.7
0.75	0.8	1.0	1.1	1.2	1.2
1.0	0.8	1.0	1.0	1.1	0.9
≥ 1.25	0.8	1.0	1.0	1.0	0.8*
Mid-period (T=0.7 s) (g)	**Mid-period Amplification Factor**				
≤ 0.1	0.8	1.0	1.7	2.4	3.5
0.2	0.8	1.0	1.6	2.0	3.2
0.3	0.8	1.0	1.5	1.8	2.8
0.4	0.8	1.0	1.4	1.6	2.4
≥ 0.5	0.8	1.0	1.3	1.5	2.0*

NOTE: Values shown with an asterisk are based on judgment.

The mid period amplifications ($T \geq 0.7$ s) apply to ground shaking affecting high rise buildings (none in Mackay at present) and other structures with similar natural periods of vibration. The mid period amplification factors for Site Classes C and D are significantly higher (around 50%) than the Site Factors in *AS1170.4-1993*.

The mid-period amplification factors are similar to those in the revision of *AS1170.4-1993* for the lowest level of ground shaking in Table 4.5. Table 4.5 additionally contains amplification factors for stronger shaking that will not be included in the revision of *AS1170.4-1993*.

The short-period amplification factors for Mackay could be higher than the those in Table 4.5, because of conditions strongly conducive to resonance in the sediments, as we mentioned in Part A. Specific periods of vibration at which the amplification factors could be higher would include the fundamental period and the lower periods (higher frequencies) of the harmonics. Amplifications at non-resonant, longer periods (periods T greater than about 1 s) may be muted compared to the factors in Table 4.5 because there is insufficient sediment thickness to generate resonant vibrations at these periods.

However, we recommend that the amplification factors in Table 4.5 are adopted for Mackay. More research is needed to develop appropriate Australian amplification factors and to improve our understanding of this potentially catastrophic resonance phenomenon involving tuned vibration between buildings and sediments in Australian conditions. The published amplification factors are largely derived from empirical data from California where basement geology is quite different from most parts of Australia.

PART C: Generation of earthquake shaking scenarios for Mackay

Earthquake shaking scenarios on rock (Site Class B)

Three estimates of earthquake hazard have been published for the region that includes Mackay (Table G.3). All estimates relate to a 10% probability of exceedence in 50 years at 'rock' or 'firm' (Site Class B) sites. This probability corresponds to an Annual Exceedence Probability (AEP) of approximately 1/475, or an Average Recurrence Interval (ARI) of 475 years. We have taken the 475-year ARI to be equivalent to a 500-year ARI for the purposes of comparison with flood and wind hazards in Chapter 5, Chapter 6 and Chapter 7.

The first estimate of hazard is found in *AS1170.4-1993* and is the one we have adopted. An 'acceleration coefficient' of 0.075 for the Mackay area was estimated from Figure 2.3 (g) of the standard. This value is equivalent to a peak horizontal ground acceleration, or PGA, of 0.075 g, where 'g' is the acceleration of a falling object under gravity. The earthquake hazard map (Figure 2.3) in *AS1170.4-1993* was compiled by an Australian Standards Committee and was a development of the work of Gaull and others (1990).

The second estimate is found in the probabilistic work of Gaull and others (1990). It is worth noting that Gaull and others (1990) treated the Mackay area as part of the eastern Australian area of 'background' seismicity because the area had 'sparse or no known seismic activity', although there is now an additional 15 years of data.

The third estimate of hazard originates from the probabilistic work of QUAKES (e.g., Cuthbertson and Jaume, 1996). They estimated a significantly higher PGA of around 0.15 g on rock, in line with their estimates of PGA for Queensland 2-3 times higher than previous estimates. Their estimate of MM VI for the 'code' scenario also indicates ground shaking at least twice as strong as the MMI estimate of Gaull and others (1990). Their value of peak ground velocity (PGV) is an order of magnitude higher than the estimate of Gaull and others.

Table G.3: Earthquake hazard for Mackay with a 10% probability of exceedence in 50 years

PGA (g)	**PGV (mm s^{-1})**	**MMI**	**Source**
≤ 0.02	≤ 20	≤ V	Gaull and others, 1990
~0.075	-	-	*AS1170.4-1993*
~0.15	~250	VI	Cuthbertson and Jaume, 1996

We generated six probabilistic, ground shaking scenarios, with average recurrence intervals of 100, 200, 475 (notionally 500), 1000, 2000 and 2500 years.

The multipliers that we used to generate the ground shaking scenario with an average recurrence interval of 500 years to ground shaking for other average recurrence intervals are shown in Table 4.6. These multipliers are provisional values used in the revision of *AS1170.4-1993* (Kevin McCue, personal communication, 2000).

The basis for our regional, probabilistic earthquake hazard estimates on rock (Site Class B) in Mackay is the response spectrum in Figure G.2 (Somerville and others, 1998). It was derived from ground motion recordings of reverse faulting earthquakes of magnitude 6.0 ± 0.6. This spectrum will appear in the revision of *AS1170.4-1993*. The spectrum describes elastic, horizontal, 5% critically damped motion of an idealised oscillator and is normalised to a peak ground acceleration of 100 cms^{-2} (approx. 0.1 g). However, for Mackay, the value of PGA with an ARI = 475 years is 0.075 g. The spectrum was therefore scaled down by a factor of 0.75 to generate our ARI = 475 year 'rock' scenario for Mackay.

Table 4.6: Provisional multiplying factors for Australian regional earthquake hazard

Average Recurrence Interval (yr)	100	200	500	1000	2000	2500
Multiplier	0.2	0.6	1	1.4	1.75	2

The spectrum was scaled up or down by the factors in Table 4.6 to generate 'rock' spectra (Site Class B) for scenarios other than ARI = 475 years.

Earthquake shaking scenarios on Site Classes C and D

Additional spectra for very dense sediments and stiff sediments (Site Classes C and D respectively) were produced by modifying the Site Class B (rock) response spectra for the scenarios with ARI = 100, 200, 475, 1000, 2000 and 2500 years with the amplification factors in Table 4.5. Figure G.3 shows the response spectra for Site Classes B, C and D in Mackay, normalised to a PGA on rock of 100 cms^{-2}.

Table 4.7 provides the PGA and spectral values for each probabilistic earthquake shaking scenario developed for Mackay.

Table 4.7: Earthquake hazard scenarios for Mackay

ARI (yr)	**Site Class B**					**Site Class C**					**Site Class D**				
		T=0.3 s		**T=0.7 s**			**T=0.3 s**		**T=0.9 s**			**T=0.3 s**		**T=1.0 s**	
	PGA (g)	**SA (g)**	**SD (cm)**	**SA (g)**	**SD (cm)**	**PGA (g)**	**SA (g)**	**SD (cm)**	**SA (g)**	**SD (cm)**	**PGA (g)**	**SA (g)**	**SD (cm)**	**SA (g)**	**SD (cm)**
100	0.02	0.03	0.06	0.01	0.15	0.02	0.03	0.08	0.01	0.25	0.02	0.05	0.10	0.01	0.35
200	0.05	0.09	0.19	0.04	0.44	0.05	0.10	0.23	0.04	0.75	0.07	0.14	0.31	0.04	1.06
475	0.08	0.14	0.32	0.06	0.73	0.09	0.17	0.39	0.06	1.25	0.12	0.23	0.52	0.07	1.76
1000	0.11	0.20	0.45	0.08	1.03	0.13	0.24	0.54	0.09	1.75	0.17	0.32	0.72	0.10	2.47
2000	0.13	0.25	0.56	0.11	1.29	0.16	0.30	0.68	0.11	2.19	0.21	0.40	0.90	0.12	3.09
2500	0.15	0.29	0.65	0.12	1.47	0.18	0.35	0.77	0.12	2.50	0.23	0.43	0.97	0.13	3.23

NOTE: ARI = Average Recurrence Interval; T = Period of vibration of ground shaking in seconds; PGA = Peak Horizontal Ground Acceleration as a proportion of g, the acceleration due gravity; SA = Spectral Acceleration; SD = Spectral Displacement.

APPENDIX H: METHOD OF ESTIMATING EARTHQUAKE BUILDING DAMAGE IN MACKAY

Our building damage assessment method comprises three steps:

- **We developed a building database categorising buildings into types based on their load bearing elements. These building types and the revised Mackay building database are described in Chapter 4;**
- **We determined the response of these building types to earthquake demand loads generated by the earthquake scenarios. Our techniques of determining building response are based on the HAZUS® (FEMA, 1999) methods and are described below. HAZUS® is earthquake loss and mitigation assessment software developed by the US Federal Emergency Management Agency (FEMA, 1999). We used the HAZUS® methods but not the HAZUS® software routines;**
- **We determined the probability of the various building types falling into damage states *nil*, *slight*, *moderate*, e*xtensive* and c*omplete* when subjected to the earthquake demand loads generated by the earthquake scenarios. The definitions of these damage states, and our techniques of determining the probabilities of their occurrence, are also based on the HAZUS® methods.**

Building types

The building types included in damage scenarios for Mackay are:

- **low-rise light timber frame;**
- **low-rise light steel frame;**
- **low-rise reinforced concrete frame & unreinforced masonry infill;**
- **low-rise reinforced masonry (concrete block); and**
- **low-rise unreinforced masonry.**

Descriptions of the building types are given in Chapter 4. The building types are designed to be compatible with the building categories of HAZUS®.

Building response to earthquake demand loads

The performance of building types is described by building capacity curves. These 'push-over' curves describe the nonlinear deformation of buildings in response to lateral earthquake forces. An example building capacity curve is shown by the red solid curve in Figure H.1. The intersection of the building's capacity curve with an applied earthquake demand response spectrum yields the peak building response in terms of spectral displacement for a particular ground shaking (demand) scenario. The HAZUS® method is similar to the static, building capacity spectrum technique of Mahaney and others (1993).

Figure H.1 demonstrates the technique using the example of light timber frame residential buildings. The response spectra that generate earthquake shaking scenarios for Mackay have been converted to the same format as the building capacity curves (spectral acceleration against spectral displacement) to enable their intersection with the building capacity curves. Preparation of the demand response spectra is described in Appendix G. The demand spectra in Figure H.1 refer to earthquake spectral shaking on Site Class D with average recurrence intervals of (a) 100 years; (b) 475 years; (c) 1000 years; and (d) 2500 years. Damping has been increased from 5% of critical to levels appropriate for light timber frame buildings undergoing the intensities of shaking generated by the scenarios. In this example they are 10% of critical for cases (a) - (c) and 15% of critical for case (d).

More generally, appropriate damping values for each building type are drawn from Newmark and Hall (1982) by the HAZUS® methodology. We used most of the damping values provided in HAZUS® to produce appropriate demand response spectra for each building type.

The capacity curve for *Precode* timber frame residences is shown in Figure H.1 (solid red curve). The capacity curve is nonlinear. It exhibits elastic behaviour for low demands (the straight line portion of the curve). Design loads will normally occur on the elastic part of the curve. For demand loads beyond the elastic yield limit (beyond the straight line portion of the curve), building response is ductile and the building undergoes permanent deformation under earthquake loading.

In HAZUS®, building capacity is modelled to be lognormally distributed. An indication of the dispersion associated with the median capacity curve for *Precode* timber frame residences associated with building capacity is shown by the red dashed curves in Figure H.1.

The capacity curve for *Post-code* timber frame residences is shown in Figure H.1 by the dashed blue curve. Both *Precode* and *Post-code* capacity curves for light timber frame residences are adopted from HAZUS®.

The intersections of the demand curves and capacity curves for each building type found in Mackay, on each site class, and for each of the six earthquake shaking scenarios, yielded values of spectral displacement that drove the building damage scenarios. An example is shown in Figure H.1. A spectral displacement of about 0.8 cm is indicated for *Precode* timber frame residences under the ARI = 2500 year, Site Class D shaking scenario.

Building damage states

The damage states for the various building types found in Mackay are described below. The descriptions of damage states are taken directly from HAZUS®. 'Small' cracks are assumed throughout to be visible cracks with a maximum width of less than 3 mm. Cracks wider than 3 mm are referred to as 'large' cracks.

Light timber frame buildings:

Slight Structural Damage: Small plaster or gypsum-board cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneer.

Moderate Structural Damage: Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.

Extensive Structural Damage: Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; partial collapse of "room-over-garage" or other "soft-story" configurations; small foundations cracks.

Complete Structural Damage: Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks. Approximately 5% of the total area of buildings with *complete* damage is expected to be collapsed.

Light steel frame buildings:

Slight Structural Damage: Few steel rod braces have yielded which may be indicated by minor sagging of rod braces. Minor cracking at welded connections or minor deformations at bolted connections of moment frames may be observed.

Moderate Structural Damage: Most steel braces have yielded exhibiting observable significantly sagging rod braces; few brace connections may be broken. Some weld cracking may be observed in the moment frame connections.

Extensive Structural Damage: Significant permanent lateral deformation of the structure due to broken brace rods, stretched anchor bolts and permanent deformations at moment frame members. Some screw or welded attachments of roof and wall siding to steel framing may be broken. Some purlin and girt connections may be broken.

Complete Structural Damage: Structure is collapsed or in imminent danger of collapse due to broken rod bracing, failed anchor bolts or failed structural members or connections. Approximately 25% of the total area of buildings with *complete* damage is expected to be collapsed.

Reinforced concrete frame buildings with unreinforced masonry infill walls:

Slight Structural Damage: Diagonal (sometimes horizontal) hairline cracks on most infill walls; cracks at frame-infill interfaces.

Moderate Structural Damage: Most infill wall surfaces exhibit larger diagonal or horizontal cracks; some walls exhibit crushing of brick around beam-column connections. Diagonal shear cracks may be observed in concrete beams or columns.

Extensive Structural Damage: Most infill walls exhibit large cracks; some bricks may dislodge and fall; some infill walls may bulge out-of-plane; few walls may fall partially or fully; few concrete columns or beams may fail in shear resulting in partial collapse. Structure may exhibit permanent lateral deformation.

Complete Structural Damage: Structure has collapsed or is in imminent danger of collapse due to a combination of total failure of the infill walls and nonductile failure of the concrete beams and columns. Approximately 25%(low-rise), 20%(mid-rise) or 15%(high-rise) of the total area of buildings with *complete* damage is expected to be collapsed.

Reinforced masonry buildings with concrete floors:

Slight Structural Damage: Diagonal hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings.

Moderate Structural Damage: Most wall surfaces exhibit diagonal cracks; some of the shear walls have exceeded their yield capacities indicated by larger cracks.

Extensive Structural Damage: In buildings with relatively large area of wall openings most shear walls have exceeded their yield capacities and some of the walls have exceeded their ultimate capacities exhibited by large, through-the wall diagonal cracks and visibly buckled wall reinforcement. The diaphragms may also exhibit cracking.

Complete Structural Damage: Structure is collapsed or is in imminent danger of collapse due to failure of the walls. Approximately 20%(low-rise), 15%(mid-rise) or 10%(high-rise) of the total area of buildings with *complete* damage is expected to be collapsed.

Unreinforced masonry buildings:

Slight Structural Damage: Diagonal, stair-step hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings; movements of lintels; cracks at the base of parapets.

Moderate Structural Damage: Most wall surfaces exhibit diagonal cracks; some of the walls exhibit larger diagonal cracks; masonry walls may have visible separation from diaphragms; significant cracking of parapets; some masonry may fall from walls or parapets.

Extensive Structural Damage: In buildings with relatively large area of wall openings most walls have suffered extensive cracking. Some parapets and gable end walls have fallen. Beams or trusses may have moved relative to their supports.

Complete Structural Damage: Structure has collapsed or is in imminent danger of collapse due to in-plane or out-of-plane failure of the walls. Approximately 25% of the total area of buildings with *complete* damage is expected to be collapsed.

Probability of building damage states

Building damage is described probabilistically for each building type by the HAZUS® methodology. Given a spectral displacement of the building type under a certain earthquake demand scenario, there is a discrete probability that buildings of that type will be in each damage state *nil*, *slight*, *moderate*, *extensive* and *complete*.

> *The probability of being in or exceeding a given damage state is modeled as a cumulative lognormal distribution. For structural damage, given the spectral displacement, S_d, the probability of being in or exceeding a damage state, ds, is modeled as:*
>
> $$P\left[ds \middle| S_d\right] = \Phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right] \quad (5\text{-}3)$$
>
> *where:* $\bar{S}_{d,ds}$ *is the median value of spectral displacement at which the building reaches the threshold of the damage state, ds,*
> β_{ds} *is the standard deviation of the natural logarithm of spectral displacement of damage state, ds, and*
> Φ *is the standard normal cumulative distribution function.*
>
> (HAZUS® Technical Manual, p. 5-35; FEMA, 1999)

Example fragility curves are shown in Figure H.2. The damage functions for each building type in Mackay were taken from HAZUS®.

We reproduce a cautionary note from the HAZUS® Technical Manual, p.5.3 (FEMA, 1999):

> *While the fragility and capacity curves are applicable, in theory, to a single building as well as to all buildings of given type, they are more reliable as predictors of damage for large, rather than small, population groups. They should not be considered reliable for prediction of damage to a specific facility without confirmation by a seismic/structural engineering expert.*

Figure H.2 shows typical fragility curves for damage states. From the figure, for a spectral displacement of 10 cm, the probability of the building type being in damage state *slight* or a more severe state is 1 (certain), the probability of the building type being in damage state *moderate* or a more severe state is about 0.5, the probability of the building type being in damage state *extensive* or a more severe state is about 0.05, and so on. The probability of being in the discrete damage state *moderate* is 0.5-0.05 = 0.45 approximately.

APPENDIX J: CONTEMPORY EYEWITNESS ACCOUNTS OF FLOODING IN MACKAY

Miriam Middelmann

Below are three eyewitness accounts of flooding in Mackay. Interviews were conducted by AGSO in February 2000 with the assistance of the Mackay Historical Society, and are not transcribed in their entirety here. Where indicated, a fictitious name has been used to maintain privacy. The first account is the memories of a girl who was twelve during the 1918 cyclone and storm surge. The second account is the memories of a mother and her son who experienced first hand the disastrous flooding in Foulden in February 1958. The third account is from an engineer whose home and business were in the Cremorne area for many years. He gives his opinion as to the causes of flooding, particularly in the Cremorne area and describes their effects.

1918 cyclone
Mrs Alice Smith (alias used)

Mrs Alice Smith was twelve years old during the 1918 cyclone. At the time of the 1918 cyclone she and her family lived in 45 Evan St, South Mackay. Her family's house survived the 1918 cyclone but was burnt down at a later date. Since then, flats have been built on the block and it has been renamed 145 Evan St. Though her family wasn't evacuated, she noted that people in Cremorne and East Mackay were evacuated.

We didn't wake up through the night. We woke up early in the morning. When we got up there was the water racing past. And I can remember as plain as anything a tank came washing down and seeing it jump up over the railway line and jump the other railway line.

There were all sorts of stuff getting washed past. We only had a sheet of iron from another place hit in the corner of our bathroom. But it was a bathroom/storeroom in those days. The kerosene and sugar were side by side in the corner of the storeroom. This sheet of iron pierced the roof and down came the water into the kerosene. And the kerosene flowed over into the sugar. That was all the damage that we had. But the water came up level with the verandah - we were just five steps up. We were watching to see if it came up any higher. If it had we were going to come up to the empty trucks. A lot of houses were just washed off their blocks.

When we got outside and saw what happened, it was really terrible. Then we had to line up for bread and everything else, organised by the Local Council.

The further towards the beach the worse off the flooding. East Mackay copped it. Houses were washed off their blocks because of the tidal wave.

1918 was the worst flood, worse than 1958, because of the big tidal wave where the river broke its banks. Out near the Toyota corner [corner of Shakespeare Street and Nebo Road, where the Commercial Hotel was]*, near the showgrounds…but by the time it came to where we were it* [the water] *wasn't very deep, but it was over the counter of the Commercial Hotel.*

I remember a piano getting washed down the road, probably wouldn't have been much good afterwards…..also animals…up past our place there were chooks and dogs and lots of things [being washed down the road]. *Nothing big like a horse* [near where our house was, but horses and cattle were swept along with the water elsewhere].

One family was practically washed out. Welch was their name. Son and his father I think was all that was left out of about five of them. Drowned. Lived down Evan Street, however a long way from where we were. In those days there weren't the houses that there are now. Not big and flash as they are now…the woman got caught in the barbed wire fence by her hair…she drowned.

The street was lined with clothes [which had been damaged by the flooding. The clothes hung on lines tied between the trees]. *Socks drying. Then they* [the shop keepers] *had sales* [to sell the clothes affected by the flooding].

The evacuated I think went to the schools, and then they had to be fed and looked after. When their whole house was destroyed then there was nothing to go back to.

[Our family] *never left our home during the cyclone. They said it was going to come again so we got ready to go up into these trucks, but it didn't happen. Everything was wet. We had the chooks up on the verandah. Dad and Jim went and got them out and put them up onto the side verandah. Everybody stayed home together. You could go out the next day or so I think. But everything was wet and soggy and that but you could go out. Of course everybody was going out to see what damage was done and that.*

The winds blew houses off their blocks and then the surge on top of that …just blown to pieces. And right the way out from here people still felt the wind. Winds and storm surge pretty much at same time. Or pretty close anyway.

The war was on then and the soldiers got word that Mackay was wiped out.

February 1958 flood, Foulden
Mrs Louisa Jenner and Mr Graham Jenner

Mrs Louisa Jenner (L) and Mr Graham Jenner (G) lived in Foulden at the time of the 1958 flood. Foulden was considered to be a disaster area following the 1958 flood so nobody was allowed to move back. Now the area is used for farming and grows sugar cane. Though the road used to follow the river up to Foulden, there is no longer a road going out there.

L: *There was about twenty houses there* [in Foulden]. *About four houses were completely washed away up the top. The river really moved over its width and took everything in front of it. There was Mrs Deseeme, down there. She was only left with what she stood up in. She was left with nothing. All* [of us] *out there, we had windmills or spears for our water. Their spears are now in the middle of the Pioneer River. The river changed its course. The flood started on the 17 Feburary 1958 at about 6 pm.*

G: *This was a high blocked house then. Dad had the dog and chooks all under the house and the dog started hitting its head on the floorboards at about two o'clock in the morning* [18/2/1958]. *So Dad walked under there at about two o'clock in the morning and there was still silt on the cement. When we were rescued at six in the morning, between our place and the house next door there was a 6 ft fence and we sort of got tangled up with this boat and this 6 ft fence and this young fella jumped out the back and gave us a shove and off we went and Dad said, "What did* *you push off?" "The ground," and Dad said "You couldn't push off the ground there was 6 ft of water there," but there wasn't. Later that afternoon there was only 3 ft of water.*

At two o'clock in the morning the river hadn't changed its course, then from two o'clock to six o'clock that was when all that silt built up and this place ended up a low blocked house, you couldn't even crawl under it. From 2 am to 6 am the river changed its course. That's when all the people had all the drama up the road….. The majority of the rain fell up at Mia Mia, in about eight hours, four inches in an hour or so…. This old fella up near Mia Mia kept emptying his gauge.

L: *The water at its peak just came over the floor under the front door into the loung*e [of our house]. *That's when I started to panic and put things up to the ceiling.*
G: *The worse thing was that we didn't know how much further the flood was to come up. But Mackay's like that. As soon as it stops raining its gone.*
L: *It* [the house] *was very well built.*
G: *The house was on 6 ft blocks*.
L: *The water would have been 6.6 ft deep, counting the timber underneath.*

L: *A lot of places did not have the phone on. We had the phone on. The phone went out very early in the morning. We packed up our things. But we only took our purse and whatever we could.*

G: *Where we lived* [in Foulden] *we were a bit low, so Dad used to drive the car up to Mrs Wall's house and put it up on the footpath whenever the river came up. But this time it got washed away*.

L: *It was a big disaster* [1958 flood]. *We thought that we were bad but a lot of others had it much worse. The water just came down in a wall and took everything in front of it…….These people* [a family] *in Foulden sat up in the fruit trees till help came to them.*

G: *Billy Patens house had debris up against the house, then the water started chewing the foundations and the house fell into a hole.*
L: *The water hit them* [the houses], *eroded* [the soil around the foundations], *and the houses fell into a hole. The terrific force of the water makes these huge holes. Then it churns…..It started about 6 o'clock at night…. There was a little house next door to us and the water was above its windows*.
G: *It fell into a hole*.
L: *It was right on the ground really. And those people were in with us. There was a house up the road and when all this happened the river come in and that. They were lucky. They took a sheet of iron off the roof and scrambled up there and sat on the roof. And did it rain, it just poured*.

G: *Paten's house fell off the blocks and they wrapped their baby up in a shower curtain and they were trying to get up onto the roof so they smashed a hole through the ceiling because the house was moving. Trying to get up through the roof they dropped the baby. She was bobbing along, but she was in the shower curtain, so she was buoyant, so she shot outside through the window. Someone grabbed her. It was pretty lucky that no one did drown up there.*

L: *McDonald was washed off and there was a banana tree floating so he grabbed it and then got to a big tree and he sat up in that. Then the Proctors threw a rope out to him and pulled him into their lounge room and they had a two storey house. The water was about 6 or 8 ft deep…..It was just a sea of water. All I could think, was would I see anybody again? Whichever way you looked out the window there was water everywhere. It is very low there*.

G: *It* [the river] *started to break its banks at the International Motors Corner*. *They done rockwork up past Foulden, but after the floodwaters dropped the water got in behind the wall and pulled it down…. I remember when dawn came and all the water was tearing down…. and the boats came up through the back….*
L: *And you know how high cane is, they just floated right over the top of that*.
G: *Then two boats came round and put Mum, Mrs* [Betty] *Collard, Morris, Rhonda and Daryl and took them over to Proctor's farm house. And then* [the men] *we got into the boat and they took us straight to Thursdan Creek. Then Betty panicked as she thought Frank had gone missing.*
L: *See, when you split up families it's hard. They took the woman and children first…. See we climbed out that corner window. And we just dropped into the boat. You couldn't get the boat up the steps here*.

G: *All these snakes and rats came up on the back steps, coming down the river, plenty of vermin.*

L: *We were evacuated to Glenella, to the big dance hall. It's still there. They have just repaired it.*
G: *Went to Glenella in boats. We were taken in big Council trucks to the hotel where we were all checked out.*
L: *Had doctors at the hotel. If you needed help, these doctors would help you*. *Robert Amos got his leg gashed. Dr Chenoworth was doing all the first aid there. This chap said "that will be alright till I get my leg checked by the doctor…" He didn't realise that he was being tended by a doctor.*
G: *Most of cane farmers had boats, and the army. They all helped.*

L: [Immediately after the 1958 flood] we stayed with friends in Glenella. Then our friends gave us a house on Cemetery Road to live in. Then we moved into our house *[in North Mackay]* in May.

L: *In the beginning of 1946 we had a flood, and they took us out by boat. The water only came up about 2 or 3 ft, and being up on high blocks it didn't worry us. Then we were taken by boats to the Glenella Hotel. I always reckoned that we should have never built there. When the tide came in the river used to break its banks.*

The Government declared Foulden a disaster area and made everybody move. My neighbours built a new house. I felt so sorry for them. They were not long married,… they had beautiful furniture…… and it just went overnight. They had nothing……They managed to salvage a few things, but once the flood goes through, you never seem to be able to get rid of that smell. You can clean it but…. You never get back what you've lost [from disasters].

We did have our furniture because the water only came over our floor. The government gave blocks of land, we balloted for them. My late husband went in and they just drew lots as to which block of land they got. Land was given all around this area. These houses were mostly housing commission houses. The people in Meadow Street, they bought their own. They got so much money to buy that ground. We just got the piece of ground plus a little bit of money. People moved to North Mackay, Bucasia, Glenella...

We were very lucky. My brother-in-law from Ilbilbie had a cane truck and he came up with his two cousins and they helped my husband pull the house down…. One weekend we had fifteen carpenters and it just went up like a mushroom. I couldn't get over it. It is exactly the same except that we had louvres along the side and we changed them over the years to windows *(Plate J.1)*.
G: *We cut it down between the studs. Dropped all the walls. Cut the floor up.*

L: *Took the roof off, dropped it and stacked it up. Like a jigsaw. We had to get another set of blocks under the house and that was ninety pounds.*
G: *It had a fibro roof and I remember Dad unscrewing the brace and bit and all the roof and only grabbed two bits of fibro.*
L: W*e had a fibro roof and ply ceilings. We still have ply ceilings in the house, but not fibro, we put an iron roof on.*
L: *There would be only three houses moved from Foulden…. These walls* [of the house] *are 5 ft high. You can't get a lot of them over the bridges….. House pieces brought over Glenella way I think, up Sugarshed Road.*

G: *My Dad used to say that a lot of women had a couple of houses built for them. My wife had the same house built twice. Three out of twenty* [houses] *moved. The rest weren't worth doing much with. The rest fell to bits, fell into a hole or that sort of thing.*

L: ***If the river was up it would come up over the Hospital Bridge, as it does still now. They had a big railway bridge beside it but they have pulled that down.***
G: *Tommy Pitts* [shop keeper], *he was opposite the Mackay Base Hospital* [in West Mackay]. *But when we ended up moving here* [to North Mackay], *he used to deliver the tucker over here to. He looked after us, the local store…..*
L: *He took your order the day before and they delivered the next day. And sometime you only used to get paid once a fortnight but you used to pay when you could.*

L: ***Nobody killed in Foulden. Cremorne there were a couple*** **[deaths].**
G: *They are not really sure who they lost in the Cremorne. There were people moving in and out all the time.*
L: ***Along the river there were shacks, I suppose you'd call them squatters. Those shacks were all washed away*** **[in Cremorne].**

L: [The flooding] *started 6 pm on 17 February and it was all over on the 18 February. It was just on dark, and the river was just running….. You were just standing there. It was up to your ankles then up to your knees, it was so swift ….*
G*: …….We went back and had a look at Foulden. It was about three or four in the afternoon* **[on the 18/2]** ***and all the water had gone.***
L: *It didn't last for two or three days. It was just overnight.*
G: *Mackay always drains quickly. We didn't stay there, just looking. We couldn't drive in there, it was all sand and silt, just walked.*
L: *When I went back the morning I didn't know the place, it had changed so much. It was a shambles. What water can do…… I couldn't believe Foulden had changed so much. It was just a heap of rubbish.*

Cremorne flooding
Mr Mick Hodge

Mick Hodge, an engineer, owned a business and home in the Cremorne and experienced a number of floods.

If you look at the problems in Mackay, most of them are man made with poor engineering and with people who do projects for that day, people without a vision. In the olden days, the first thing that we did when we interfered with the river was we built the director wall down the middle of the river. The idea of that was good at the time as it was designed to direct the current to the southern bank and cut off a third of the river. It done two things, it scoured the river up nicely and kept the southern bank navigable for the transport we had at the time, and it also built Cullen Island, the big sand bank, and blocked the river again.

The director wall when it was originally built was only a stone wall. It had a height equivalent to about a 21 ft tide or 22 ft tide. From that level we blocked off a third of the flow. Since then the water has steadied on the downstream side, it's filled up all the mud flats and now all the mangroves have filled up. Now a third of the river is effectively blocked off altogether for flood, hence we are getting a bigger afflux upstream until the director wall is moved. The director wall healed all water to the southern bank and caused huge damage to East Mackay. And it flooded all the public utilities, all the City Council's utilities, all the workshops, all the main roads and the powerhouse. So it shows you that something changed [in the river] *and it was the effect of the director wall. While it was doing one good thing, and still does a good thing, it stops the river from meandering around, and that's sacred now, no-one can move it, it's owned by Mackay Harbour Board* [it has caused inundation of buildings]. *While it is a monstrosity now it was a good idea. It would be silly to move the director wall completely, because you only need to drop it down, because it still stops the river from meandering.*

They then built a railway bridge across the river. They planned to trellis it from bank to bank [across the floodplain] *but they decided that they had to build it cheaper, so they used cheap landfill* [instead of piles], *which formed an embankment and therefore dammed the water, flooding everybody upstream and scouring everything downstream. See, as this low level bridge was built and as the Pioneer River is full of debris, the bridge was packed with debris as soon as it was submerged. So you couldn't get a drink of water on the other side of it. So we had a complete dam built right across the river. So we objected to it for years, but because it was built by the officials it didn't dam the water!*

The first flood which gave any damage to us in the Cremorne was in 1940. It was most damaging to us. It was only a small flood. It banked right up against the railway line. A lot of people had their houses on the ground. All of our chickens were on the ground and nine horses were tied up on the flat and the flood drowned all of the horses and chickens. The flood came unexpectedly at 2.30 am in the morning. One of my friends had a humpy there. Most of the houses were humpies then, and he heard a strange noise and he put his foot out of bed and he was up to his knees in water. It came right into his house at 2.30 am in the morning. It was unexpected then.

At that time we objected [to the damming and flooding]. *But the war was on. So we had a meeting about it with the Mackay Harbour Board, the State Government and the Railway Department and they admitted liability, but there was a war on. So they got away with it.*

Then '42' flood, then '44' flood, then '46' flood was a bigger flood, but we were building our houses up higher so there was less damage. So that time we had another big pow wow at the railway station. The railway and the Mackay Harbour Board was represented. I am the last living person in that delegation. The building of a river model was promised. However, we didn't get anything. In 1951 we got a higher flood. Cullen Island was building up. So we put up with the '51' flood. They then commissioned the Queensland University Professor [then Dr] *Gordan McKay. He built the river model and he wrote a report. And that report was damming. The director wall, the railway embankment and the Forgan Street Bridge are singularly not causing the full damage. But collectively they are a monstrosity.*

The director wall caused another problem. In the olden days every old engineer made cylindrical piles. Nowhat the angle the water hits it [the bridge] *from, you get flow. In the 30s we streamlined* *all our piles. It was a wonderful idea so long as the current remained constant from that angle. But they had built a director wall at an angle. So when they designed the piles on the Forgan Street Bridge the director wall was already there. But they didn't take it* [the director wall] *into account. So the piles are at a different angle to the flow. Therefore it acts like a aircraft wing. The water hits it* [the piles] *at an angle and transfers force and digs out from the back. Hence in the '58' flood we dug out the piles of the Forgan Street Bridge and part of the bridge fell down. It was an error. And that's causing an afflux. The current hitting it and changing direction causes another afflux. The hydraulic mistake that the Forgan Bridge represents. It's a prize for the idiots. But you can't blame the bloke who designed it, because he was given a plan of the river without the director wall in it. So the combined effect of the railway bridge, the director wall and the Forgan Bridge give us terrific high floods. So we put up with that until the 1970s, when they moved the railway bridge. Since the railway bridge was moved the floods in Cremorne should have been lowered by at least a metre.*

Now if you want to ask me about the floods. We had two effects of the floods in the Cremorne area: we had the ponding effect on the upstream side, and the increase in current velocity that dug all the houses out on the eastern side as it did in the Foulden flood. I think it dug three to five houses out [in Cremorne]. *The speed of the current as it went over the railway line was so high that it dug those houses out. They didn't get washed away, they got scoured out. Where we were we had steady water. So when you get an obstruction like the director wall, like the railway embankment or road embankment, you get a steadying effect on the upstream side and a scouring effect on the downstream side. So the unfortunate people are on the downstream side. They don't get as high water but the speed of the water is faster and it digs out everything around them.*

Fortunately we never had those two main creeks [of the Pioneer catchment, Cattle Creek and the Pioneer River] *hit maximum flood together. We have never yet had the Gooseponds* (Plate J.2) *and Pioneer River flood* [at the same time]. *The danger to Mackay is the Gooseponds. Have a look at what happened when we duplicated the Ron Cam bridge. We lifted the carrageway up feet and left the unfortunate business people there and we have a little bridge across Gooseponds, that's Jane's Creek. Fortunately in the Cremorne, the old timers in the twenties we either built our bridges high and trellised it, or built it low and let the floods go over it. But in the 30s something happened to our intelligence and we built the bridges halfway and the bridges blocked up. In the older days we had three culverts through it and we were smart and we then started building the roads above the flood height.*

The '58' flood in the Pioneer River ran about 260 000 cusecs. That's their figures. And they said that it is possible for the Pioneer River to run 500 000 cusecs. And I challenged Professor McKay on that saying " that it's impossible, because every tributary to it would run backwards. All the creeks would run backwards up to Walkerston and what would be Homebush would disappear". Imagine the volume of the water you would have to have to do that. Once you get it [the Pioneer River] *up to around 300 000 cusecs all the water would run backwards, because that is the capacity of the banks. Our banks couldn't carry more.*

I had freehold property in the Cremorne – engineering business (Plate J.3). *We lived next door to the business and a lot of our staff lived around us. But we had a lot of unfortunate people there. See, we had the poor people of Mackay in the Cremorne. Cremorne had a very big population in the 30s. My Dad was good to them. We used to look after them. They were all our people. They all had little humpies or tin sheds under the mangroves. The population in the Cremorne then was about 500. We had a bakery, two corner stores, a hotel and a poultry business and naturally it was all washed away.*

My house was high set, about 10 ft above the ground level. During the '58' flood the water was about 0.8 m below the floor. A cow went under the house and its' horns raked the floor. There was 7 or 8 ft of water over the carriage way of the road. Our place was a refuge [during flood]. *We used to take the people in because the houses around were low. See, only about three houses were high set. Our place used to look like a League of Nations in all the floods. By the '58' flood the humpies were already gone – lost during the earlier floods. In the 1958 flood we lost about fifty houses in total. A few dozen little houses and humpies were lost, plus a corner store, dance hall, an upholstery shop, and the Cremorne Hotel.*

I put a deputation to the Pioneer Shire asking them for support on the floods. The deputation said that we've got to do something. We've got to build up *[our buildings]* or you've got to drop the man-made structures. I rang the Mackay Harbour Board up and ordered 2500 cubic yards of overburden and hired five trucks *[to lift my business up higher by filling underneath]*. We jacked the business up higher and higher. It was an achievement. We lifted the business up 5 ft and maintained production all the time. Put a new roof over the top and kept working. But it cost thousands and thousands of dollars to fill. Incidentally the Council wouldn't give me a permit so I built it without a permit anyway, though they threatened to prosecute me all the time. Built *[the ground up]* about 1.8 m – higher than the road. One of the 1970s floods flooded the business because of the railway bridge. The water covered our floor but gave us no damage. But it won't be flooded anymore because the floods are lower by 1.5 m *[because of the removal of the railway bridge]*.

Incidentally I led the Cremorne people and we didn't pay our rates because we didn't get any service so we didn't pay. This went on for two years and then I got a call from the Shire Clerk one day and he said "Mick, the Council is going to sell up all the Cremorne". I said "That was interesting. I don't know anybody who would want to buy in the Cremorne". And I told the Council that "Until you give us some service and grade our roads we won't pay our rates". The road was all scoured up by floods, 4 ft holes. Nobody had touched the road for years. Yes, we had town water, but incidentally when we went to the Cremorne they wouldn't give us town electricity as some of the Council didn't want us to move there. So we only had three horsepower. We got town power in about 1939. Then I got a call from the Council saying "you'll have a grader in the morning by 9 o'clock". And I said, "Mr Chairman, when the grader comes at 9 o'clock we will pay our rates by 10 o'clock". And from then on we had no problem. Every year they'd grade our road and we would pay our rates.

But we got another problem. Everytime they build a road up the water going over the road is effectively cut off. They haven't woke up to themselves yet. The Mayor has spent millions of dollars raising the streets, so the people camp on the street as the people's houses are lower than the street.

In 1962 I tried to plan to help Mackay. We had a big argument in town about draining the river. In the 1958 flood all the low areas were flooded. There was a great argument in town. The Mayor I said to him "Until we get enough brains to drain the river south, you are going to have this problem". I wanted them to make the network of roads flat, lower than the people, draining the water south. You need wide streets, you need to put a wide based drain and let the water run down the streets so it won't do any damage. But they lift the streets every year and the town is getting flooded out.

If they moved the director wall, then the river would drench itself, because it is currently blocked by the effect of the director wall, sand and mangroves. The Mackay Chamber of Commerce tried for years to let the sand people move Cullen Island but it didn't work because of the engineers receiving a percentage of cost.

The bottom of Barnes Creek is solid rock. The Pioneer River has drifted as far north as it can. Over the centuries the river has moved up from Homebush. See, in the '94' flood the river used to go around the bottom end of Gordon Street but in the flood it moved north. The river has come right over and hit against a rock wall, Rockleigh. In the eastern Cremorne it is all rock. They had three acres of land down there and they had a swimming pool, toilets and all the recreation for Mackay. Big rock pools. In 1936 the Showmans Guide and the Show Association had a disagreement, and the whole of the side shows went over to the Cremorne. But that all went with the scour of the water, we lost all that.

The Councils after the '58' flood swapped land in various places around Mackay. So people moved from the floodplain, especially from Cremorne [and Foulden], *mostly to North Mackay around Quarry Hill. Swapped land* [north of the river] *for their land* [on the floodplain]. *They couldn't swap their land for land south of the river. About three big houses moved. Some of the others demolished their houses, wanted to go the other way. People sold their blocks of land or just left them. Cremorne just deteriorated then, but it is growing again now. In 1970 flood, Hodge was about the only business house left in Cremorne.*

I reckon that when you see unfortunate people as in the Cremorne, people invested their whole life's savings in a piece of dirt and a house and to see them lose it. And you've got to remember that it doesn't hurt the rich much. And as I said in a public letter "I couldn't worry about Hodges', because we could afford to live in the Cremorne. We have never put in any flood claim. We could afford to live there, but what about the poor unfortunate people that can't afford to get out".

APPENDIX K : CONTEMPORARY REPORTS OF THE FEBRUARY 1958 FLOOD

The following material of the major flood in Mackay in February 1958 is taken from the Mackay *Daily Mercury.*

The Daily Mercury, Monday, February 17, 1958

HEAVY FLOODING IN CITY

Wet season starts with more than foot of rain

MAIN ROADS CUT

Large sections of Mackay city and suburbs were under a foot or more of water at noon yesterday.

Coastal areas to the north were blocked by the Gooseponds which was 2 ft over the bridge at Evans Avenue and about a foot over in Malcomson Street at 2 p.m. yesterday. At 9.45 a.m. the flooded Pioneer River cut off traffic over the hospital bridge. By 4 p.m. the level had risen to more than a foot and rising. At 6 p.m. it rose sharply to 4 ft and was maintaining that level at 10.30 p.m. At the Gooseponds late yesterday, a P.M.G. truck was stranded in shallow water with a wet engine at the Malcomson Street Bridge while attempting to get three poles which had been knocked over by a landslide on the road to Glenella…..In the centre of the city at the Victoria-Wood Street intersection pedestrians were walking knee deep across Victoria Street. At the Victoria Street – Wellington Street intersection water was lapping a car door packed near the kerb, and was 7 or 8 in deep in Crawford's corner store. In Goldsmith Street, East Mackay at 6 p.m. water was about 3 in above floor level on the front door of a low blocked home. In West Mackay Bridge Road near the Fourways intersection many streets were flooded from fence to fence. Water was lapping entrances in the Fourways shopping centre and goods on floor level at the rear of the premises were moved to higher positions.

DEATH IN FLOOD

Tail lights burning under water led Mackay police to a drowned man in a small sedan car submerged in the Gooseponds on Saturday night.

The man was Denis Laurence Matthews (23), fitter, of Forsyth Street. He went off the approaches to the Malcomson Street bridge over the Gooseponds at approximately 9.45 p.m. No one saw the accident. The car, which went off the left hand side of the bridge outbound, was completely covered by 8 ft of water which was lapping the decking of the bridge at the time. At 10.40 p.m. Douglas Miller, of Malcomson Street, was driving across the bridge when he saw the tail lights of the submerged sedan.

Second car in

As he backed up to investigate, another sedan travelling outbound left the approaches to the bridge and plunged into the Gooseponds. Its nearside wheels lodged on the top of the submerged car. The five men in the second car, which was driven by Bruce Graham, of Farleigh, escaped injury. They reported the accident to the Mackay police and requested a crane to lift their car out. When the crane had dragged out Graham's car it "fished" for the still glowing tail lights of Matthew's sedan. Diving was impossible because of the muddy water. A rope finally was hooked under the offside rear springs of the submerged car and at 12.15 a.m. the crane hauled it to the *surface. Matthew's body was found over the rear of the driver's seat facing the back. Police said last night rain could have obscured visibility on the bridge which had no handrails.*

The Daily Mercury, Tuesday, February 18, 1958

POLICE EVACUATE AT CREMORNE
River breaks into city:
Mirani bridge collapsed:
Finch Hatton awash
CRITICAL TODAY?

About 50 people were evacuated by police last night from the Cremorne and Harbour Landing areas, as the Pioneer River broke its banks.

Others evacuated privately following police radio warnings, which began at 9.30 p.m., of flood danger in the low-lying areas adjacent to the river in the city reach.

Into City

After 11 o'clock the river broke its bank on the city side of River Street. By 11.40 it had flooded Carlyle Street to 8 in over the crown of the road and had entered a store on the Victorian-Carlyle Street corner. Late last night City Council engineers predicted that to 3 a.m. the river would maintain its level of 24 ft at Forgan Bridge with possibly slight rises. At 1 a.m. it was maintaining 24 ft in spite of a falling tide. They predicted a critical period at 11.40 a.m. at the top of the 18 ft 2 in tide on the river today. Two families were evacuated from Town Beach and picked up in Rae Street by an army lorry and taken to private accommodation for the night. Residents in the Marajou area on the Farleigh side of the Hospital Bridge were evacuated for safety to Glenella and Farleigh last night. Water was over the main road at Foulden. The flood in the river was slapping the under section of the floor at Michelmore's over the river………………… About 11 o'clock at the top of a 16 ft 6 in tide in the river, the flood water submerged Barnes Creek Road at Cremorne between the Buffalo Hall and the Hotel. At 11.30 p.m., when a press car left the area, the water was about 6 in over the road and running fast.

Army truck

At 11.30 p.m. the river was lapping under the railway bridge but had not broken the River Street bank. Police used an Army lorry to transport pensioners and families to an emergency refuge at the Wood Street Salvation Army Hall. Salvation Army officers said the emergency centre would remain open throughout the night for the people flooded from their homes. Captain V. Brown, of the Salvation Army, remained with a police crew in the Army lorry ready for further evacuations. At the hall, evacuated families and old people were settling down for the night with blankets. Salvation Army members were arranging to supplement food the evacuees took with them when they left their homes. A police radio truck which had been on standby in the Cremorne area withdrew at 11.30 p.m. to Forgan Bridge. Police roped off danger areas at Cremorne. Residents had left low-lying homes to sleep in the Cremorne Hotel. They stacked furniture and belongings above flood level in their homes before leaving. Residents were expecting the worst flood in nearly 20 years.

"Looks bad"

Cremorne shopkeeper Mr. D. Wells said as he and his family prepared to leave their home for the Cremorne Hotel "It looks really bad tonight. I've been here for 18 years and I've never seen it look like this. The water tonight is coming at us from the south. All other times it has come from the west". Police borrowed Mackay Surf Lifesavers' rescue boat and left it ready for any emergency at the hotel.

LATE NEWS

At 1.45 a.m. today, the Pioneer River was running 26 ft high at the Forgan Bridge gauge, and rising. Water was racing down Brisbane, River, Carlyle, and Tennyson Streets. Police were patrolling the lower reaches of the flooded streets in boats.

City registers 28.95 inches of rain in four days

TRANSPORT OUT OF CITY BLOCKED

Sharp rise in Pioneer River

Rainfall in Mackay had totalled 28.95 inches in the four days to 9 o'clock last night since the wet season started on Thursday.

The official recording at the Mackay aerodrome was well under a private reading of 32 in on a city gauge for the same period. The drome figure put Mackay's rainfall at 15.20 in in the 24 hours to 9 a.m. yesterday followed by a further fall of 4.65 in in the next 12 hours.

River rise

Yesterday's rain was sufficient to maintain local flooding in the city area, but heavy falls in the upper reaches were followed by a sharp rise in the Pioneer River early last night. At the aerodrome the official registration for the 48 hours ended 9 a.m. yesterday was 21 in 55 points (pts). Of this, 15 in 20 pts fell in the 24 hours to 9 a.m. and in the next 12 hours to 9 p.m. a further 4 in 65 pts were recorded. In the 24 hours ending 9 a.m. yesterday a private gauge showed a reading of 18 in 69 pts From 9 a.m. to 8 p.m. a further 3 in were registered.

Flooding yesterday had caused a complete blockage of air, road and rail transport out of Mackay and shipping schedules were disrupted. The aerodrome which was closed at 3.30 a.m. on Sunday remained closed all day yesterday. Classes in many schools were cut by more than half. One of the worst affected schools in the flood area was North Mackay, which had an attendance of 90 out of 450. The lowest attendance for one class was four. There was a full roll up of teachers. The Eimeo road section of the school near the Gooseponds was under water. Many schools in the district were shut. Wind direction changed from east, southeast to east and later in the afternoon to south, southeast. Velocity varied from 12 to 25 knots.

Filled yards

It was a repetition of Sunday in the suburbs and city as water from flooded storm water drains filled back yards, gutters and streets inches deep. The heavy rain eased off at 6 p.m. and late afternoon sun tried to break through the heavy overcast but by 7 p.m. it was raining heavily again At the Mackay bulk handling terminal, manager (Mr. H. W. Burkitt) reported leakage in the main shed was "nothing to speak of". In the shed was 89 200 tons of sugar and the bulk vessel Ninny Figari (bound for the United Kingdom), which has been berthed in Mackay since Saturday, could not be loaded until the weather cleared.

All roads out of Mackay were blocked by flood waters during the day and the R.A.C.Q. advised motorists not to travel.

North of Mackay the roads were blocked at the Gooseponds, both in Malcomson Street and Evans Avenue. The Evans Avenue route was impassable, but heavy trucks negotiated the Malcomson Street Bridge. The swift wash prevented cars from crossing until about 6 p.m. when the water was falling…

The Daily Mercury, Wednesday, February 19, 1958

FLOOD RECORD

Beat 1918 level

SIX HOMES, HALL LOST

Worst floods in the history of Mackay which exceeded the 1918 cyclone levels were receding slowly last night.

About 180 people evacuated by police parties from their floodbound homes on Monday night and yesterday spent the night in dry areas of the city. At least six homes and the Buffalo Hall at the northern approach of the Forgan Bridge are known to have been swept away. City business houses entered by the flood water have suffered heavy stock and plant losses. Thousands of acres of rich canelands along the Pioneer River flats were inundated. Erosion losses are expected to be heavy. In the city area, the Pioneer river broke its banks before 8 a.m. to flow down Nebo Road and through business and residential areas, leaving the immediate city area a virtual island.

Rescued

First contact with North Mackay was made after 5 p.m., when crossing of flooded sections could be made on foot and by boat. Flooding in the area was reported to be relatively light. At Foulden Mr. A. E. Zunker crossed the racing river current in a rowboat to rescue an elderly couple marooned on the roof of a dangerously tilting house. Three houses were washed from their sites in the Foulden area and three in the Cremorne area. Rail, road and air communications in and out of Mackay were cut and about 1000 telephone subscribers were cut off.

Record level

Crisis period for Mackay yesterday was between 9 a.m. and 11 a.m. At 9.30 a.m. flood level at the Forgan Bridge was at a record 30 ft…Heavy flooding in south and east Mackay yesterday was mainly caused by the river breaking its banks between the western end of Victoria Street and the Commercial Hotel. About 6 a.m. a sheet of water rushed down Shakespeare Street and to a lesser extent down Gordon and Alfred Streets, flooding the railway station area and areas further south. In the south Sydney, east Shakespeare and Keats Streets areas water rose about 3 ft in half an hour. It covered fences in South Sydney Street and Keats Street. Late last night streets in the area were still covered by about 2.5 ft to 3 ft of water and was dropping very slowly, Sewerage systems were out of order but temporary arrangements had been made by the City Council on Monday.

RIVER ROSE A FOOT OVER 1918 LEVEL

The Pioneer River yesterday rose above the recorded levels of the 1918 cyclone.

Peak level of 30 ft at the Forgan Smith Bridge yesterday morning was about one foot above flood level recorded at the bridge site in 1918. Working from flood survey maps, consulting engineer Mr. C. N. Barton last night put the general level of yesterday's flood in residential areas as one foot above the 1918 level. According to the plans yesterday's flood was a foot higher at the Commercial Hotel corner. It was also a foot higher at the lower (western) ends of Victoria and Gordon Streets. In 1918 the flood is not recorded as having broken over Milton and Peel Streets. In 1918 the river broke its bank and crossed Nebo Road at the northern end of the Showgrounds. There was conflicting evidence about water at the southern end of the showgrounds. But yesterday the showgrounds were completely flooded to knee depth and portion of the fence along Nebo Road was tilted by the force of the water. Mr A. Grant who was in Mackay during the 1918 flood, said from his observations the level of water today was much the same as in 1918….

Station off air

Normal services of Mackay's commercial radio station, 4MK, was disrupted because of a failure through water at the Mt Bassett transmitting station.

The gas main in North Mackay was severed in six places by floodwaters in the Pioneer River for the first time in history. Workmen were unable to begin repairing the damage until the water level had subsided sufficiently at 6 p.m.

RESCUERS EVACUATE ALL CREMORNE AREA

Rescue teams yesterday evacuated 120 people from the Cremorne area.

They had stayed overnight in their homes and in the Cremorne Hotel during the areas most severe flood battering to date. Floodwaters washed away three homes and the Buffalo Hall. Sixty people had been evacuated by the police to the city area on Monday night. Yesterday they were forced to wait until floodwaters had dropped sufficiently before starting the second evacuation operation at 3.45 p.m. Police and civilians led by the officer in charge of the Mackay Police District (Inspector R. V. Woodbury) brought women and children from the verandah of the Cremorne Hotel by boat, and guided men along a rope chain to the end of the Forgan Bridge.

Eight men led by Mr. R. Wormald, radio mechanic of West Mackay, had fought their way with a rope through the river, still dangerously high, to a power pole 50 yards away. The rope was then anchored to the pole and carried through fast flowing water to the next anchor point – the service station. From there the rope was taken over the road to the hotel. The last boatload from Cremorne was safely on the Forgan Smith Bridge at 6.20 p.m. Approach road to the bridge was completely washed away with big slabs of bitumen torn up by the force of the water. The fast flowing river had demolished the Buffalo Hall at 7.30 a.m. yesterday. All that was left was a piece of buckled dance floor just above the surface. A wooden barrier around a service station nearby was smashed and buckled.

Poles over

Along the length of the Harbour Road from the service station, power and telegraph poles leaned with their lines hanging in the water. Cremorne Hotel, which sheltered thirty men and women at the height of flood was covered in debris and its sagging front verandah showed signs it had been damaged by the flood. Along the riverbank adjacent to the hotel were gaps from which houses had been carried or damaged by the force of the flood. Many of those rescued told pathetic stories of the loss of not only their homes but everything they possessed. Mrs E. Morrow, of Palm Street, her two daughters and husband spent the night in the hotel and watched their house swept away at 6 a.m. Mrs Morrow said: "We have lost everything apart from a portmanteau of clothes. We lost our furniture, house and even my daughter Lynette's glory box. She is due to get married next month. We have lived in Cremorne for twelve years and have survived other floods. But we never want to settle in Cremorne again".

Lost ₤2000

Mrs A. Wells, who, with her husband, owns a small shop opposite the Cremorne Hotel said: "It was a night of terror. It was not only our losses but those of the other poor people in the Cremorne, too. We (herself, husband, son, daughter-in-law and two children) have only the clothes we stand up in Mr. Wells said he estimated his loss of stock, house, furniture, refrigeration and such at over ₤2000. Some were more fortunate. Mr. and Mrs. L. Herman, with *their 18 months old daughter, said after the rescue the water had only lapped the floorboards of their high blocked house and there had been no loss of furniture. However, an outhouse had been lost and fowls drowned. The 30 people who stayed in the hotel told a tale of hunger and fear. The kitchen was flooded and locked and many had not eaten since lunchtime on Monday. Apprentice fitter R. Malone, of Shakespeare Street, who went to help and remained to be stranded on Monday night, gave his description of the end of the Buffalo Hall: "At 6 a.m. the outhouses at the side of the hall went. An hour later, the back of the hall started to collapse, then the right side, and finally it collapsed completely. As the wreckage drifted downstream it hit a section of the approach to the railway bridge, lifted the line and twisted it over." Of the night in the floodbound hotel, Mr. Malone said, "throughout the hotel it did not look as if the building would go, but the water rose 4 ft up the wall. Everybody evacuated the ground floor and moved to the upstairs section. There was no food and all we had were a few lollies, some cake and prunes. Asked why people did not take advantage of the evacuation on Monday night, Mr. Malone said they thought they would be safe in the hotel.*

POWER FAILED

North Mackay was without electric power during most of the flood ordeal yesterday.

Power to the North Side failed at 5.15 a.m., and had not been restored last night. A Regional Board spokesman said it was thought the failure was because a pole had been washed out…..

The Daily Mercury, Wednesday, February 19, 1958

TWENTY FORCED OUT OF FLOODWATERS

Pensioners were forced to leave their cottages in East Mackay yesterday.

Working from three out-board motor dinghies, two policemen and a number of civilians successfully evacuated 20 aged pensioners from their cottages in MacArthur Street between 8 a.m. and 10 a.m. as floodwaters 3 and 4 ft deep swept through the area…..The evacuees were taken to a high blocked house in Ready Street. The water here was just as deep but the house was well above its level. After the evacuation was completed a five-ton Army transport truck, which was being used in rescue operations, churned through flooded streets with food supplies for the pensioners. Manned by Constable G. A. Williamson and civilians, the truck made its way along flooded Shakespeare Street into Prospect Street, which was under 3 ft 6 in of water, and Evan Street, which was a raging torrent….There was heavy general flooding in South and East Mackay areas. Parts of Hucker, Wentford, Prospect, Goldsmith, Gold, Evan, Shakespeare, Byron Park, Porter, Moore and Ready Streets were 5 ft under. By late afternoon the water level had dropped to about 4 ft

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AS WE SAW IT

Things got into some funny places during the flood crisis hours. Among them was the pushbike left hanging over a signpost at the Shakespeare-Goldsmith street corner.

A bicycle rack in the middle of Carlyle Street yesterday afternoon looked out of place – the road was only open to swimmers and boats.

Jack O'Brien, waterside worker, of Shakespeare Street, received lacerated wounds and abrasions to the right shin when he stepped into a manhole which had been uncovered by water.

The Daily Mercury, Thursday, February 20, 1958

BIG FLOOD LOSS
SEVENTEEN HOUSES DEVASTED AT FOULDEN
At least three houses were swept away and 14 wrecked or badly damaged when the full force of the flooded Pioneer River hit the settlement of Foulden on Tuesday.

Foulden, on the northern bank of the Pioneer River was completely isolated by road, rail and telephone until yesterday morning. Dozens of people in the area were homeless yesterday and more than 12 modern vehicles were upturned and buried in the sand. Acres of sugar land were flattened, part of the Foulden road was washed away and parts of the main northern railway line were feet deep in sand.

Clothes only

Residents who had been rescued by boat returned to their mud, silt and sand covered homes when flood waters receded yesterday in an attempt to rescue property. Many had lost all their belongings except the clothes they were wearing at the time of the flood. Last night all had been accommodated at hotels or at the homes of friends. Foulden felt the full force of the flood when the river burst its banks and smashed into the road about 5 a.m. on Tuesday.

During the peak of the flood,

- ***People were rescued from drowning.***
- ***Houses with people inside or on the roofs were swept yards by the current.***
- ***People scrambled into the high branches of trees to safety and livestock were drowned.***

Motor transport was unable to get to the settlement yesterday because of the sand covered road on the northern approach to the Pioneer Bridge. Residents rescued were taken to the Glenella Hall from where they obtained other accommodation. They paid tribute to the energies and generosity of police and civilian helpers.

CLUNG TO TREE

During the Tuesday flood a man, his wife and three sons spent nine hours clinging to the branches of an orange tree with only one orange which was growing on the tree for food. They were Mr G.A. Nielson and his family who yesterday were trying to salvage property from their wreaked home. In driving rain yesterday morning, Mr Nielson said he expected to suffer a complete loss from the floods. At 10.30 on Monday night water first entered his low blocked house, so he swung two wire mattresses from the cross beams of the roof, inside the house, and placed his wife and children on them.

Bashed hole

When flood waters continued to rise he bashed a hole in the side of his house and struggled with his family to an orange tree in the backyard of next door neighbour Mr. Clarence Reeves. When trying to get to the tree, a three-year-old son, Paul, was washed away and almost drowned. Mr. Nielson said he managed to get his son to the tree. Other members of the family had been temporarily pinned inside the house by swirling furniture and timber. They sat in the orange tree from 6 a.m. Tuesday until they were rescued at 8 p.m. Included in his flood losses was a wallet containing fifty or sixty pounds, he added. When the water receded his house was a smashed *wreck of timber, furniture and mud. About 5.30 a.m. a fibro house belonging to Mr. Colin Macdonald with about 16 people inside was swept from its 8 ft high blocks and carried about 100 yards by the current. The occupants tore a strip of iron from the roof and clambered outside where they were safe from the water. Miss Margaret Lemberg (18) was knocked off the house and spent 1.5 hours clinging to the branches of a fig tree. Mr. MacDonald also took refuge in the tree.*

Baby fell in

A three-weeks-old baby, Kathleen Paton, daughter of Mr. and Mrs. Paton fell in the water swirling outside the house but was rescued by Mr. Royce Atherton. She was revived with artificial respiration. The six roomed house of Mr. Clarence Reeves, his wife and five children, was smashed when flood waters hit it and tilted it on a dangerous angle into a crater scoured out at the side of the house. Mr Reeves said, as he was carrying possessions from the house yesterday, that he had broken a hole in the ceiling of his house and placed his wife and family on the roof about 2 a.m. Tuesday. His car was buried in sand in the backyard of the house. He estimated his total loss was about ₤4000.

TWO DEAD, ONE MISSING AFTER CREMORNE FLOOD

Two men were found drowned in the Cremorne area early yesterday morning and a woman is missing, presumed drowned.

The men were: Edward Lee McCarthy (40), labourer, of Cremorne, and Michael Francis Piggott (36), labourer, also of Cremorne. The missing woman is Lilly Peters (or Peterson), aged about 65, also of Cremorne. To late yesterday no other fatalities had been reported to police. Extensive inquires had been made in the worst of flooded areas and no further persons were reported missing.

Found bodies

Bodies of the drowned men were found by Mr. Vernon Chilly, of Mt. Bassett, at 7 a.m., about half a mile from the northwest end of Palm Street. The bodies were about 50 yards apart and about 150 yards from a small house which collapsed late on Monday night or early Tuesday morning. Police presume that the two men had taken refuge in the house. It is believed the missing woman was also in the house when it collapsed. Police inquires and searches yesterday found no trace of the missing woman……

LIMIT ON WATER SUPPLY REMAINS

City water pumping stations will not be back in full operation for 'some days'.

Mackay is still being restricted to a maximum water consumption of one million gallons a day, following the flooding of pumping stations on Tuesday. Yesterday both pumping stations at Nebo Road, flooded on Tuesday, were pumped dry. The City Council was endeavouring to dry the motors and switch apparatus. The Regional Board transformer, which was also put out of commission, due to flooding, was still unable to be fixed yesterday…..The Council has not had to restrict the use of the sewerage system in spite of floodings of some pumping stations.

OVER BOWSERS

…Men yesterday were clearing mud and silt from the Pioneer Service Station at the northern approaches to the Pioneer Bridge. Manager (Mr. W. Jocumsen) said the floodwaters had swept over the top of the 6 ft petrol bowsers. About 6 a.m. there was a sea of water as far as the eye could see to the north. The bitumen had disappeared and there was from 2 ft to 5 ft of sand across

the road for about a mile. During the flood at least one car had been hurled against a tree and buried….

SURFMEN HELPED

Mackay lifesavers worked an 18-hour stretch during the critical stages of the flood at Cremorne on Tuesday. The surfmen were asked to assist in the flood rescue by Mackay police chief (Inspector R. V. Woodbury).

APPENDIX L: SEQUENCE OF FLOODING IN MACKAY, PRIOR TO LEVEE CONSTRUCTION

The following material is taken from a report for the Pioneer River Improvement Trust (McKay and Gourlay, 1962) and describes the sequence of flooding in Mackay, prior to levee construction.

The first areas flooded were the cane fields and swamps of West Mackay, the swamps in the Cremorne-Barnes Creek area and the Foulden farming area. Flooding then occurred in the low-lying residential and commercial areas of Mackay, particularly in the vicinity of River Street, Shakespeare Street, Cremorne and low-lying areas of North Mackay. Extracts from McKay and Gourlay (1962) follow:

1. River Street flooding

Floodwaters first spill over bank into River Street between Michelmore's store and the Railway Bridge when the Forgan Bridge gauge reads 13.5 ft. This represents a discharge of 100 000 to 130 000 cusecs at Pleystowe depending on the tide. This water flows in a southeasterly direction across Carlyle, Victoria and Tennyson Streets to Lawson Street, where it flows through culverts in the railway embankment to the Sandfly Creek area. This is what occurred during the flood on 8 February 1954 **[7.45 m GH at Mackay].**

As the flood rises further, spilling into River Street occurs downstream of the Railway Bridge and River Street is inundated from just downstream of the Forgan Bridge to Tennyson Street. Since the culverts through the railway embankment are of small size and the area to the east of the embankment is filled with water entering from the river via Sandfly Creek, the floodwaters now back up behind the railway embankment. When the water exceeds that of the river bank between Tennyson and Byron Streets, water flows back into the river. This was observed during the floods on 11 January 1951 **[8 m GH at Mackay]** ***and on 31 March 1956*** **[7.85 m GH at Mackay]…**

For still higher floods such as on 18 February 1958 **[9.14 m GH at Mackay]** ***the river overflows upstream of Forgan Bridge between the bridge and the Harbour Board office and water flows across the Sydney Street intersection down River Street towards Lawson Street. Floodwaters now overtop the railway embankment from a point near Alfred Street to the river and spill into the Sandfly Creek area. It is not absolutely certain whether water returns to the river between Tennyson and Byron Streets as before, as it appears that the general flow here is parallel to the river across the railway embankment with some flow in a southerly direction into Sandfly Creek in the vicinity of the Butter Factory. Under these conditions, the flood level in the city to the west of the railway embankment becomes relatively constant while that in the Sandfly Creek area increases with the size of the flood. Flood levels in River Street where the initial flooding occurs also increase with flood magnitude. No water entered the area to the west of the embankment from the Shakespeare Street breakthrough during the February 1958 flood owing to the higher level between Shakespeare and Alfred Streets near the railway goods yard.***

The period of inundation of the city is difficult to determine as it depends very much on the drainage characteristics of the area, as well as on the tide and the rate of fall of the

flood. However, the period that the river is actually spilling at River Street, ie Forgan Bridge level is greater than 13.5 can be determined. It varies from four hours on 8 February 1954 to 18 hours on 18 February 1958.

The river level at Fisherman's Wharf is not known accurately but it appears that it was 4 to 5 ft. lower than that at Forgan Bridge at the peak of the February 1958 flood and about 2 ft. lower for January 1951 and March 1956 floods.

The general behaviour of the 1946 flood is different to the above in the following respects:

1. ***No overflow occurred upstream of Forgan Bridge even though the gauge reading was 18.18 and the ground level here is 17.1.***
2. ***No return flow into the river appears to have occurred until some distance downstream of the Butter Factory, the bank between Tennyson Street and the present Fisherman's Wharf being above flood level.***

The first of these discrepancies could be accounted for by an error in the Forgan Bridge flood level. A value of 16.18 would be more consistent with other flood data. The second is probably due to the fact that on this occasion there was a bridge in the railway embankment with a considerably larger waterway area than the culverts, and the water did not bank up behind the embankment.

2. Sandfly Creek flooding

Floodwaters in the Sandfly Creek area come from three sources:

1. ***Backwater from the river downstream of Fisherman's Wharf; this includes the effect of the tide.***
2. ***Water from River Street flowing through or over the railway embankment.***
3. ***Water from Shakespeare Street breakthrough flowing down Shakespeare Street and crossing the railway line between Shakespeare Street and Stevenson Street.***

Flood levels in the area will be influenced by the tide height (the area is extensively flooded during high spring tides) and the magnitude and duration of the flood, the latter factors having a predominant effect.

3. Shakespeare Street flooding

Both during the 1918 **[8.86 m GH at Mackay]** ***and February 1958 floods, water spilled over the high bank in the vicinity of the intersection of Shakespeare Street and Nebo Road in West Mackay. Little is known of what happened in 1918 as the issue is confused by the flooding the day before from the storm surge. However, in 1958 it is known that large areas on either side of Shakespeare Street were flooded. The general movement of floodwaters was east through the city along Shakespeare Street, vearing south after crossing Wood Street to cross the railway line between Shakespeare Street and Stevenson Street. The floodwaters then merged in the Sandfly Creek area with water from other sources. The depth of the floodwaters ranged from about 1 to 3 ft.*** **[31 cm to 92 cm].**

From the above descriptions it can be seen that the general movement of floodwaters, and the areas inundated, in Mackay are quite clear. However, information is

inadequate on the flood level of the river in the vicinity of the Butter factory (Fisherman's Wharf) which makes the design of protective works for the River Street area difficult. Also the problem arises as to which area suffers the most from a flood. For instance, the River Street area has been flooded eight times since 1918, and there have been some close shaves. The Shakespeare Street area has been flooded only twice during this period. During the February 1958 flood the depth of flooding was generally greater in the River Street area while a greater area and many more people were affected by flooding in the Shakespeare Street area.

4. Flooding in Cremorne and North Mackay

Relative little specific information is available concerning flooding in this area. General movement of floodwaters appears to be that water overflows the director wall upstream of Cremorne and then divides, one current flowing towards Barnes Creek, the other flowing between Cremorne and the director wall under the Forgan Bridge. When the capacity of the Barnes Creek Bridge waterway is exceeded, water banks up behind the road embankment and then overtops it (February 1954 flood). Higher floods (1946, 1951, 1956 and February 1958 floods) overtop the railway embankment, which then acts as an overflow weir. This embankment was washed out during both the 1946 **[8.04 m GH at Mackay]** ***and 1951 floods. While the railway embankment is overtopped, it is not certain whether the Barnes Creek Railway Bridge is overtopped also. Levels for the 1956 flood indicate that it was not on that occasion, but it seems that it*** **[the Barnes Creek Railway Bridge]** ***was overtopped during the February 1958 flood.***

A comparison of flood levels for the February 1958 flood and ground levels in the North Mackay area indicates that floodwaters must have flowed from the Cremorne-Barnes Creek area across Malcolmson Street and Evans Avenue into the Gooseponds and Vines Creek. The depth of water would have to be no more than one foot **[30.5 cm]*****, probably less…***

APPENDIX M : MACKAY CYCLONE HISTORY

This list has been compiled from several sources, most notably an unpublished list compiled by Jeff Callaghan of the Bureau of Meteorology (Callaghan, 1999), a database of cyclone tracks developed by the Bureau's Severe Weather Section in Brisbane (BoM, 1999) and Appendix 1 in Harper (1998).

Cyclones which passed within 75 km of Mackay are shown with their date in **bold**; those which passed between 75 and 150 km of Mackay are shown with their dates underlined. More distant cyclone for which tracks within 300 km or for which an impact on Mackay has been recorded are also included.

2 March 1867

An unnamed but severe cyclone brought gales and did much damage to Bowen, 160 km to the northwest. Whilst we have found no reported impact from Mackay, the 5-year old settlement almost certainly suffered some impact.

30 January 1870

An unnamed cyclone of unknown strength probably crossed the coast between Mackay and Bowen. Given the damage in Bowen and subsequent flooding in Peak Downs and Clermont inland off Mackay, it is likely that damage was caused in Mackay.

30 January 1884

An unnamed but severe cyclone (Category 3?) crossed the coast near Bowen (160 km north-west). Severe flooding was reported from Mackay and a 3 m storm surge was recorded at Poole Island in Edgecumbe Bay south-east of Bowen.

17 February 1888

An unnamed cyclone (Category 3?) recurved just east of Mackay with severe winds demolishing several houses. The *Geelong* ran aground with the loss of two crew and the *Youyang* was dismasted.

4 February 1898

Cyclone *Eline* (Category 3?) recurved over Mackay causing extensive destruction and flooding. Many buildings including the Court House and two churches, were destroyed whilst many others were damaged. The major flood caused the Pioneer River to shorten its course by 4.8 km (its present course). The lowest barometer reading was 984 hPa.

28 January 1910

An unnamed cyclone (Category 2-3?) which had originally crossed the coast around Cape Tribulation north of Cairns before re-crossing the coast near Townsville and degenerating into rain depression. Major flooding was experienced in Mackay.

10 January 1911

An unnamed cyclone, which had originated in the Gulf, had degenerated to a rain depression before it passed about 400 km to the west of Mackay bringing heavy rain and some flooding.

11 February 1911

An unnamed (Category 1-2?) cyclone paralleled the coast from the Cape to Mackay bringing heavy rain and flooding. The rain depression finally crossed the coast near Mackay.

23 March 1911

An unnamed (Category 1-2?) cyclone recurved to the east of Townsville before paralleling the coast to the southeast. By the time it reached the Mackay area it had degenerated into a rain depression centred about 200 km off shore.

16 January 1913

An unnamed low category cyclone (Category 1-2?) recurved to within 200 km to the east of Mackay. No reports of damage have been identified.

4 April 1913

An unnamed low category cyclone (Category 1-2?) paralleled the coast within 250 km to the east of Mackay. No reports of damage have been identified.

8 February 1915

An unnamed, but low category (Category 1-2) cyclone paralleled the coast passing within about 70 km of Mackay. No reports of damage for Mackay have been identified, however, considerable damage was experienced in Bowen.

10 December 1915

An unnamed cyclone (possibly Category 3) which approached from the north, probably within 75 km, hit Mackay. Winds bent iron telegraph poles double and damaged roofs in the town.

27 December 1916

An unnamed severe (Category 3?) cyclone crossed the coast near the Whitsunday Group about 110 km to the north. The lighthouse on Flat Top Island off Mackay was severely damaged. After moving inland this cyclone brought disastrous flooding to the Clermont area with the loss of 62 lives.

14 December 1917

An unnamed (Category 1-2?) cyclone crossed the coast perhaps less than 50 km to the north of Mackay, bringing gales and heavy rain. No reports of damage in Mackay have been identified.

21 January 1918

An unnamed severe cyclone (Category 4) crossed the coast just to the north of Mackay. The central pressure was less than 933 hPa. An estimated 1 200 houses were destroyed and very few surviving buildings escaped damage. The cyclone crossed the coast at close to (a relatively small) high tide and the 3.6 m surge that accompanied the cyclone caused great damage and accounted for at least 13 of the 30 people who lost their lives. Heavy rains which followed the cyclone gave rise to the second highest flood on record for the Pioneer River two days after the storm tide.

5 April 1921

An unnamed severe (Category 3) cyclone crossed the coast in Broad Sound having passed about 140 km off Mackay. No reports of damage in the town have been identified.

8 February 1926

An unnamed (Category 1-2?) cyclone recurved off the coast from Townsville. It approached to within 230 km of Mackay. No reports of damage in the town have been identified.

21 April 1928

An unnamed (Category 1) cyclone recurved near Mackay and Broad Sound. No reports of damage in Mackay have been identified.

20 February 1929

An unnamed (Category 1) cyclone recurved off Townsville and approached to within 250 km of Mackay. No reports of damage in the town have been identified.

26 February 1929

An unnamed low category cyclone which had originally crossed the coast at Mossman (north of Cairns) recrossed the coast near Mackay before re-intensifying. No reports of damage in Mackay have been identified.

28 January 1930

An unnamed (Category 1) cyclone recurved to the east of Mackay. Minor flooding occurred in the town.

1 February 1931

An unnamed (Category 1?) cyclone which paralleled the coast from the north-west approached to within 230 km of Mackay. No reports of damage in Mackay have been identified; however, this cyclone eventually caused serious flooding in Brisbane.

19 January 1932

An unnamed (Category 1?) cyclone which tracked from the Gulf to the east of Townsville caused serious flooding between Mackay and Cairns.

27 December 1933

An unnamed (Category 1?) cyclone in the Coral Sea recurved to within 250 km to the east of Mackay. No reports of damage in Mackay have been identified.

27 March 1938

An unnamed (Category 1-2?) cyclone recurved to within 150 km of Mackay. Gales, high seas and torrential rain were experienced. The outer harbour, which was at an early stage of construction, was damaged and some bridges were washed away.

27 January 1939

An unnamed (Category 1?) cyclone crossed the coast about 100 km to the south of Mackay. No reports of damage in Mackay have been identified.

17 March 1940

An unnamed cyclone (Category 1-2?) crossed the coast at Mackay from the north. Storm force winds were recorded at Mackay but no reports of damage have yet been identified.

3 April 1941

An unnamed Category 1 cyclone paralleled the coast from the north within 140 km of Mackay. No reports of damage in Mackay have been identified.

30 May 1941

An unnamed Category 1-2 cyclone, tracked from the north to within less than 100 km from Mackay. No reports of damage in Mackay have been identified.

8 February 1942

An unnamed Category 1-2 cyclone crossed the coast from the east about 100 km south of Mackay. No reports of damage in Mackay have been identified.

16 February 1942

An unnamed Category 1-2 cyclone which had crossed the coast near Cardwell moved out to sea north of Mackay. No reports of damage in Mackay have been identified.

30 January 1943

An unnamed Category 1 cyclone crossed the coast near Broad Sound, about 190 km to the southeast of Mackay. Coastal flooding was experienced between Mackay and Maryborough.

12 February 1943

An unnamed Category 1 cyclone crossed the coast from the north at Mackay. No reports of damage in Mackay have been identified.

7 March 1944

An unnamed Category 1 cyclone recurved about 260 km to the east of Mackay. No reports of damage in Mackay have been identified.

5 March 1945

An unnamed category 2 cyclone which had formed in the Gulf recrossed the coast at Bowen, 160 km to the north-west. No reports of damage in Mackay have been identified.

18 January 1946

An unnamed low category cyclone (Category 1-2?) crossed the coast in Broad Sound, around 110 km to the south after having tracked from the north and passing within 90 km of Mackay. This cyclone produced a major flood in the Pioneer River.

4 March 1946

A Category 1 cyclone, which had first touched the coast near Innisfail on the 2nd , tracked along the coast within 80 km of Mackay. No reports of damage in Mackay have been identified.

10 February 1947

A Category 1 cyclone crossed the coast in Broad Sound after having tracked within 100 km to the east of Mackay. A major flood in the Pioneer River was experienced.

15 February 1949

An unnamed Category 1-2 cyclone crossed the coast north of Cooktown and then recurved to recross the coast at Mackay. Significant flooding was experienced in the north of the State, however, no reports of damage in Mackay have been identified.

15 January 1950

An unnamed Category 1 cyclone that first recurved near Cooktown in Far North Queensland subsequently tracked southeast parallelling the coast. It passed within 160 km to the east of Mackay. No reports of damage in Mackay have been identified.

11 March 1950

An unnamed Category 1 cyclone crossed the coast at Camilla, about 90 km south of Mackay. This cyclone had tracked within 75 km to the east of Mackay. No reports of damage in Mackay have been identified.

8 February 1954

An unnamed Category 1 cyclone crossed the coast near Townsville before tracking within 150 km inland of Mackay. Widespread major flooding was caused.

7 March 1955

An unnamed Category 3 cyclone passed directly over Sarina, 60 km to the south of Mackay. Widespread structural damage and heavy rain was experienced. A storm surge of 0.5 m above the predicted astronomical tide has been reported.

20 January 1956

An unnamed Category 1 cyclone crossed the coast near Airley Beach, 140 km to the north before degenerating to a rain depression inland of Mackay. No reports of damage in Mackay have been identified.

6 March 1956

Category 3 cyclone *Agnes* tracked along the coastline from Townsville to the Whitsunday Group before moving to the east. It brought strong winds and torrential rain to coastal areas. The rains produced a major flood in the Pioneer River and a storm surge of 1.4 m above the predicted astronomical tide has been reported.

10 January 1957

An unnamed Category 1 cyclone crossed the coast just to the north of Mackay. No reports of damage in Mackay have been identified.

1 April 1958

A small, but intense, unnamed Category 3 cyclone crossed the coast to the south of Bowen. Tornadic outbursts and major flooding were experienced in Mackay. A storm surge of 0.5 m at Mackay has been reported.

16 February 1959

Severe Category 3 cyclone *Connie* crossed the coast near Guthalungra near Ayre before tracking south. It was still at Category 2 level when it passed around 80 km to the west of Mackay. Floodwaters caused damage to several bridges including undermining of the Forgan Bridge. A storm surge of 0.5 m at Mackay has been reported.

16 April 1964

Category 3 cyclone *Gertie* recurved to the north-east of the Whitsunday Group bringing it within 250 km of Mackay. Extensive coastal flooding was experienced.

6 December 1964

Cyclone Flora (Category 1?) formed in the Gulf and crossed into the Coral Sea near Innisfail before tracking down the coast. By the time it reached the Mackay region it was heading to the east and was about 240 km north-east of the town. No reports of damage in Mackay have been identified.

17 January 1970

Small Category 3 Cyclone *Ada* passed through the Whitsunday Group. Severe damage was experienced in the area close to the track and the Pioneer River reached major flood levels. The track passed within 80 km of the city at its closest point.

16 February 1971

Category 2 cyclone *Gertie* passed within 80 km of Mackay on a north-westerly track before crossing the coast near Cardwell. Only minor damage appears to have resulted, though a storm surge of 0.3 m above the predicted astronomical tide at Mackay has been reported.

20 February 1971

Category 1 Cyclone *Fiona* tracked from the Gulf to cross the coast near Rockhampton, passing about 100 km to the west of Mackay. Apart from bringing heavy rain, a tornado destroyed a house near Sarina.

18 December 1973

Category 1 Cyclone *Una* crossed the coast near Townsville before tracking south. It passed within 210 km to the west of Mackay and caused major flooding in the Pioneer River and a storm surge of 0.4 m above the predicted astronomical tide was recorded at Mackay.

18 January 1974

Category 1 Cyclone *Vera* recurved in the vicinity of Townsville, passing close to the Whitsunday Group and within 110 km to the north of Mackay. No reports of damage in Mackay have been identified.

16 January 1975

Category 2 Cyclone *Gloria* which formed close to the coast near Cairns, tracked southeast taking it within 360 km to the north east of Mackay. The main impact was flooding at Mackay and Lucinda.

19 January 1976

Severe Category 3 Cyclone *David* crossed the coast north of St Lawrence, around 110 km south of Mackay. No reports of damage in Mackay have been identified, though a storm surge of 0.6 m above the predicted astronomical tide was recorded at Mackay.

5 March 1976

Category 1 Cyclone *Dawn* developed in North Queensland and tracked along the coast passing within 30 km to the west of Mackay. Two houses were unroofed in North Mackay.

28 April 1976

Category 2 Cyclone *Watorea* tracked parallel to the coast at a fairly constant distance of around 180 km from the Cairns area to Fraser Island. No reports of damage in Mackay have been identified.

9 March 1977

Category 1 Cyclone *Otto* formed in the Gulf and crossed into the Coral Sea near Cape Tribulation before making landfall near Bowen. It tracked within 125 km of Mackay. No reports of damage in Mackay have been identified.

11 January 1979

Category 1 Cyclone *Gordon* crossed the coast as a rain depression about 80 km north of Mackay. No reports of damage in Mackay have been identified.

1 March 1979

Category 1 Cyclone *Kerry* crossed the coast near Proserpine, about 80 km north of Mackay. Significant wind damage was suffered by at least 26 houses in Mackay (a maximum gust of 76 knots was recorded in Mackay) and huge seas caused $1 million (1979 dollars) damage to boats in the harbour. Hinterland roads were blocked by landslides. A storm surge of at least 1 m was recorded at Brampton Island in the Whitsunday Group close to the track of the eye and a surge of 0.7 m was recorded at Mackay.

7 January 1980

Category 1 Cyclone *Paul* moved from the Gulf to enter the Coral Sea at St Lawrence to the south of Mackay. This track brought the cyclone within 40 km of Mackay. Major flood levels were achieved in the Pioneer River.

24 February 1980

The track of severe Category 3 Cyclone *Simon* brought it within 200 km of Mackay. Whilst significant damage was experienced in the area between Heron Island and Hervey Bay, only limited effects appear to have been experienced in Mackay.

26 February 1981

Category 2 Cyclone *Freda* formed near Cooktown and tracked south-east. It was around 360 km off Mackay and caused a 10 m trawler to founder 300 km east of the city. The crew of 4 was rescued.

4 March 1983

Category 2 Cyclone *Elinor* crossed the coast in Broad Sound where it produced a storm surge of 1 m. Two yachts were lost near the coast to the south of Mackay.

22 February 1985

Category 1 Cyclone *Pierre* paralleled the coast approaching to within 75 km off Mackay. No reports of damage in Mackay have been identified.

1 March 1988

Severe Category 3 Cyclone *Charlie* crossed the coast near Ayr before degenerating rapidly as it moved south. It produced very heavy rainfall that caused major flood levels to be reached in the Pioneer River. A storm surge of 0.6 m was recorded at Mackay.

4 April 1989

Severe Category 4 Cyclone *Aivu* crossed the coast at Ayr, some 230 km north-east of Mackay. Its main impact on Mackay was major flooding in the Pioneer River.

25 March 1990

Cyclone *Ivor* was a Category 3 system when it crossed the coast at Princess Charlotte Bay. It then crossed to the Gulf, recurved to again enter the Coral Sea at Cairns before weaving its way down the coast to the south of Mackay as a rain depression. Heavy rain produced major flood levels in the Pioneer River.

26 December 1990

Severe Category 4 Cyclone *Joy* eventually made landfall near Townsville (as a Category 2 system) after harassing the Cairns community for several days. Early on 27th a tornado at Mackay demolished two houses and damaged another 40. Extensive damage was also done to a sea-side caravan park. One person was drowned at Mackay whilst attempting to surf in the cyclone-generated seas. Some rainfall stations in the Pioneer River catchment recorded around 2 m of rainfall between 23 December and 7 January.

19 January 1994

Cyclone *Rewa*, which reached Category 4 at its most intense, approached to within 240 km to the east of Mackay at Category 2 intensity, before turning away to the south. Mackay emergency managers were on alert to begin evacuations of low lying areas of the city because it appeared likely that, given its consistent westerly track during the 18th, it would impact on the city. No damage eventuated in Mackay.

27 January 1996

Rapidly forming Category 3 Cyclone *Celeste* approached Bowen from the north before turning out to sea. Its track brought it within 180 km of Mackay. Significant damage was experienced in the Whitsunday Group, however, limited damage was reported in Mackay.

9 March 1997

Severe Cyclone *Justin* (Category 4 at its peak) was a very large and long lived storm. In its early stage, whilst coming no closer to Mackay than 450 km, it generated massive seas and a storm surge that was recorded on the Mackay Port tide gauge to be 0.5 m above the predicted astronomical tide. Peak waves of 8.45 m (trough to crest) were recorded off Mackay. Significant coastal erosion was experienced along all of Mackay's beaches.

APPENDIX N: CONTEMPORARY REPORTS OF THE 1918 CYCLONE

Below are three contemporary reports of the 1918 cyclone. The first account, from the *Mackay Daily Mercury,* describes in some detail the impact of the cyclone on the city of Mackay. The second and third accounts describe attempts to communicate the plight of Mackay to Brisbane and elsewhere.

The following material is taken from the account of the January 1918 cyclone published in the *Mackay Daily Mercury* on Saturday 26 January 1918.

A GREAT CYCLONE

MACKAY AND DISTRICT DEVASTATED

Fifty-five inches of Rain in 83 Hours

Destruction of Raw Sugar Stocks
and Sugar Mills

Damage Estimated at £1 000 000

It will be twenty years on the 3rd of next month when the cyclone, known as Eline, wrought considerable damage to Mackay. A far more serious visitation of a similar kind occurred this week. When daylight broke on Monday morning last the inhabitants, who had spent a thrilling night, were able to witness what the wind is capable of doing when its force increases somewhat beyond the ordinary [Plate M.1]. *No one who has passed through the experience of the present week will ever forget the Mackay cyclone of 1918. The noise of the violent rainfall, the collapse of buildings and the grating of iron as it was torn from its position will probably remain a nightmare for a long time to come. It was unsafe to move from a safe shelter for several hours on Monday morning because of flying sheets of iron, and when this ceased the inhabitants were equally endangered by the rising flood waters which seemed to be spreading everywhere. A brief description of what the cyclone effected is given below. We have not attempted in this article to describe the damage done to the business houses of the town; that must be left to another issue for the work of destruction was so complete that none seemed to escape, not even the largest and most substantial buildings - Barne's fine block in Sydney Street, for instance, collapsed; Marsh and Webster Ltd. had their beautiful plate glass windows destroyed and the attractive block in Victoria Street, newly erected, and known as Dalrymple's buildings, faired like all the others. Probably no business house, whether large or small, escaped scatheless. To add to the discomfort of the people the gas and water both failed. The gas* *works were inundated by the flood waters and the pumping station also. The water supply was restored yesterday afternoon but it will be some days before gas will again be available.*

The first warning reached Mackay on Sunday afternoon. Further messages received at intervals during the night stated that the gale was approaching Mackay, also that it was dangerous, and heavy rain might be expected. On receiving the late advices nautical men expressed the opinion that the centre of the disturbance would pass over the Flat Top and this proved correct. About midnight on Sunday the condition of things began to look serious and the barograph at the Post Office registered the unprecedented reading of 27.90. The instrument does not register lower than that reading but private instruments registered 27.86. The force of the wind at this time would be about 120 mile an hour. Naturally damage commenced to be inflicted over a wide area. The ornamental trees in the principal streets were uprooted, and although it was pitch dark, the sound of flapping iron on the roof of public and private buildings and flying sheets indicated that those places were being unroofed or demolished. When daylight appeared iron was being carried great distances like so many pieces of paper and those aerial flights made it dangerous to emerge from cover. Heavy rain accompanied the wind and both increased in severity as minutes passed. The cyclone continued with unabated force until 8 o'clock when the centre passed and with it a change of the wind to the north. The change of direction brought no abatement to the hurricane conditions; instead the wind blew with greater violence. Much of the damage that was inflicted corresponded with the change in the wind. The southeast gale had partially or wholly destroyed many buildings and had severely shaken the portion that remained intact. When the gale shifted around to the north it completed the work of destruction. A lull occurred late in the afternoon which seemed to indicate the cyclone had spent itself so far as the town was affected and that it had passed away. The damage was practically over, and it was very extensive. During the night heavy rain commenced to fall. The lull in the wind and the heavy rain buoyed the stricken town with the hope that the end of their troubles were in sight. But it was not so. The rain continued almost incessantly until noon on Thursday. The rainfall for this period may not be a record for Australia, but there are very few occasions which exceed it. Between 8 o'clock on Sunday night and 10 o'clock on Tuesday morning 24.70 in were registered; from 10 a.m. to 5 p.m. on Tuesday, 9.20 in; from 5 p.m. till 9 a.m. on the 23rd, 8.05 in; to 9 a.m. on the 24th, 13.61 in, making a total of 55.56 in 83 hours. For the succeeding 24 hours the rainfall was 68 points.

The barometer readings were: Sunday 9 a.m., 29.659; 3 p.m., 29.476; 9 p.m., 29.371. Monday 9 a.m. 27.90 (the barograph does not register below this reading, but as explained elsewhere, the register fell four points lower); 1.30 p.m., 29.123. Tuesday 10.20 a.m., 29.686; 4.45 p.m., 29.615. Wednesday 9 a.m., 29.177. Thursday, 9 a.m., 29.628. It will be noticed that the cyclone reached its greatest force between 9 p.m. on Sunday and 1.30 p.m. on Monday.

The destructive period of the cyclone was about ten hours and it was almost incredible the amount of damage that was done in that short period [Plate M.2]. *Some of the residents are able to report that not a pane of glass was damaged in their homes, but they are very few. Of the 1200 or 1400 houses within the Municipality of Mackay, not more than one quarter escaped damage of some kind, and in a great many cases the buildings were levelled to the ground. The town on Monday afternoon presented an appalling spectacle. The damage in most cases consisted of the houses being unroofed, and this particularly applied to the larger buildings such as hotels, churches, public halls and two-storeyed buildings. As with other classes of buildings some of them collapsed entirely and some sustained partial damage only. The residential area suffered severely. A great many of the residences were thrown down and completely destroyed, while others were unroofed or otherwise damaged. No particular part of the town suffered more than any other part. The damage was general in town and country and confirms the opinion that the centre of the cyclone traversed the district.*

SOUTH WARD

The South Ward had its full share of the disaster. The low areas in the ward became inundated more rapidly than other parts of the town, and when the destructive force of the cyclone on the buildings was added to the inundation by storm water and the tidal wave the deplorable conditions that prevailed must be left to the imagination. Many thrilling rescues were effected and many lives were saved in an almost miraculous manner. Our limited space will not permit us to attempt to describe the sensational experiences of very many residents in that ward.

CHURCHES AND HALLS

A visit to the churches revealed a spectacle saddening to all. Many broken windows and a damaged northern wing represented the damage at the Presbyterian Church, but the Sunday School adjoining was levelled and the manse suffered severely. The Church of England, one of the prettiest churches in town collapsed and practically every thing inside was destroyed, including a valuable pipe organ. The Sunday School also gave way, and the beautiful ornamental trees in the grounds were either blown down or stripped of their foliage The Rectory also suffered severely. The Catholic Church weathered the storm fairly well, but the same cannot, unfortunately, be said of the Convent School which was demolished [Plate M.3]. *The German Lutheran Church was stripped of its roof and portal, and is off its blocks at one end. At one time the building was poised at a very precarious angle, but the wind changed and righted the structure.*

Practically all that remains of the Theatre Royal is the floor and a portion of the covered-in overhead structure. The stage and screen could not be located. The whole of the covered-in portion of the Olympic was blown away, and a portion of one wall collapsed and fell into Wood Street [Plate M.4]. *The Britannia Hall escaped with the loss of a few sheets of iron, but in strong contrast to this was the Freemasons' Hall close by, which was totally demolished. The Star Theatre was almost unroofed, especially above the stage. At the rear of this building St. George's Hall was unroofed. In common with all iron structures the Star Court suffered severely, the only wall standing being that in Victoria Street.*

THE HOTELS

Practically all the hotelkeepers suffered severely. Our space makes it impossible to give a detailed description of the havoc wrought, but the following brief outline will convey some ideas. The Belmore Arms Hotel was completely unroofed. The balconies of the Post Office Hotel collapsed and the greater portion of the roof was blown away. The Prince of Wales and Tattersall's Hotels were partially unroofed; the Riverview Hotel and Crown Hotel, situated in close proximity in River Street, were completely unroofed, while the balconies of the latter collapsed and most of the walls fell in leaving practically a shell. The balconies on Barry's Hotel were demolished, but the roof stood good. Most of the iron on the balconies and roof of the Grand Hotel was blown away, and the damage inside was very heavy. Wills', the Railway, and the Federal stood the storm very well and the damage outwardly was very slight. The Palace, opposite Wills', was sheered of its balconies, part of its roof, etc. going. Ready's was partially unroofed. The Metropolitan was completely unroofed, while part of the framework fell inside, causing great damage. Pearson's and the Queensland, had most of the iron blown away while the balconies of the Victoria were demolished. The Pioneer was unroofed and the iron from the greater part was blown away. The balconies of both the Australian and the Queen's were completely demolished and part of the roofs blown away. The Gympie collapsed altogether and the Cremorne across the river was almost demolished. On Nebo Road the Commercial Hotel, Brewery, Shamrock and Caledonian suffered more or less heavily.

THE RIVER

While the cyclone was at its height another terror, in the shape of a tidal wave, swept the town and caused consternation amongst the fear wracked householders. It struck the coast about 5 o'clock when the cyclone was raging and it is alleged a wall of water 25 ft. high swept over the beaches; and taking a southwesterly direction submerged the town to varying depths as far out as the Nebo Road. It was five or six feet deep on Beach Road and about two feet deep at the Ambulance corner. The water flowed inland in waves, carrying debris of a substantial character with it. In the river the wave played havoc with the shipping, wharves, stores and houses, while a large section of the Sydney Street bridge, which is the main avenue between Mackay and North Side, was washed away [Plate M.5]. *The Brinawarr and a barge were lying tied up to Adelaide wharf. At 6.30 the force of the wind and tide carried the two boats away. Captain Hine and his son W. Hine, together with the cook W. Burrows, were aboard the ship, but were powerless to do anything in the face of such a tempest and when the Binawarr struck the bridge she was so badly knocked about that she sank. In the meantime, Captain Hine and the other two men clambered on to the bridge and thus escaped with their lives. For some time a portion of the vessel was seen above the swirling waters but in the flood on Tuesday it disappeared entirely. The barge was joined later by the 'Tenior Tay (?)', and there the two remained until the bridge gave way, when they drifted up the river and stuck on the northern bank above Mr C. Palmor's property. The tug Pelican and the Harbour Board barge Alice May were piled up on the end of the bridge near the Cremorne, and are now high and dry. The smaller vessels suffered almost total destruction, with the exception of Mr. J.M. Kingwell's launches, one of which, the Florence, was landed on the bank above the bridge, and the other, the Bellita, floated up in front of 'The Folly', and there remained.*

The wharves from Michelmore and Co's store down to Howard Smith were submerged to a depth of several feet, and the contents of the sheds were washed out into River Street and those running at right angles, where after the flood waters had subsided piles of articles barricaded the roadway and against them were piled debris of every description. The main wharf adjoining Michelmore and Co's store was demolished and lower down, a shed containing 500 tons of sugar was practically stripped. The main building of Paxton and Co. suffered comparatively little damage, but the wharf and store were badly knocked about. At the Adelaide sugar shed the water rose up to the third tier of sugar, while a portion of the roof was blown away and the water streamed down on the sugar causing a great deal of damage. In a portion of the building the water did not enter except in flood and most of this sugar, it is expected, will be in fair order. The coal bunkers were washed away, with a quantity of gear, and the coal scattered all over the street. The front of the building is littered with debris, and a number of coal trucks are standing on the line, blown from the Beach Siding by the hurricane at a terrific rate. The big Harbour Board pump 'Mick Berly (?)' is also stranded in the middle of River Street. A barge was sunk on the slip adjoining the wharf. The Bond and Queen's wharf were wrecked, and the Government steamer Relief sunk at her moorings. The sheds along the river bank were washed away, and the building at the Pilot Station which housed a lot of material used by the Harbour Master in connection with the marking of the river. All that is left is a whale boat and another small craft.

The heavy rain, combined with the big tide, caused a record flood in the river on Tuesday. There is no authentic record as to the height the river rose, as the gauges were all washed away, but the Harbour Master (Captain Greenfield) states that the water rose at least 20 ft. The lower portion of the town was inundated to a depth of .... The river broke across below Devil's Elbow into Barnes Creek and relieved the pressure in the main outlet, and on Thursday morning the back water in the land near the cemetery overflowed and crossing Nebo Road, rushed down Shakespeare Street and a parallel street to a depth of 3 ft. It is the opinion of experienced men that had this second diversion not occurred the loss of life would have been enormous. The flood commenced to subside on Thursday afternoon and is already back to normal.

The buildings along River Street, apart from those mentioned, are all more or less damaged, the worst being the hotels, Anvil Stores, Mr. Hossack's premises, Mr Ungerer's blacksmith's shop, and a small shop opposite the Adelaide wharf, which was completely demolished.

HOUSING THE REFUGEES

During the early hours of Monday morning people whose houses had been demolished, or were in danger of early destruction, sought refuge with friends. Many were accommodated in this way, but as the work of destruction continued hundreds found themselves homeless. Speedily the Ambulance, Technical College, Ready's Rooms, Town Hall, Red Cross rooms, School of Arts, Fire Station, Drill Shed and Catholic Club rooms together with the larger private dwellings were requisitioned and the refugees were given shelter. At the Red Cross rooms, women and children were assisted with dry clothing as most of them left their homes too hurriedly to even clothe themselves fully.

It was when the refugees commenced to arrive that some of the worst features of the tempest were revealed and it became known that serious loss of life had occurred.

One of the first deaths recorded was that of Mr Robert Morton, engineer on the Government steamer Relief. On Monday morning the water surrounded his dwelling on the river bank and fearing the worst, and seeing the tide gradually rising, he climbed into the ceiling to make a hole in the roof where his wife and daughter could seek shelter. It was while in the ceiling that the building collapsed and he was killed. Mrs. Morton and Miss Morton managed to escape and swimming with the current were carried in the direction of Mr Weir's residence, where a landing was effected.

Mr J. Shanks and his brother Mr Frank Shanks, also had a terrible experience. They resided in the old butter factory and when the tidal waters entered the building took refuge in what they considered the strongest room in the house and put their wives and families on a table. The water rose above the level of the table and another one was placed on top and as the waters still continued to rise chairs were provided. When everything seemed secure, the kitchen from the house adjoining collapsed and partly demolished the building where the people were. Mr Frank Shanks was rendered insensible through being struck by falling timber and all were thrown into the water. Mr J. Shanks then heroically secured rafts and ultimately, after a fierce battle with the elements, and a most perilous journey, during which his wife and children and his brother's baby disappeared, he reached the Waterside Workers Hall and gained entrance through a window. Mr Frank Shanks afterwards reached Tennyson Street and upon his information a rescue party was organised and a number of people, including Mr. and Mrs. Weir and several who had sought refuge in their residence, together with those who were in the hall, were rescued. The force of the rain was terrible, Mr Shanks remarking that he was bruised all over with the driving rain and had every stitch of clothing ripped off his body.

The family which appears to have suffered most so far as loss of life is concerned, is that of Mr Peter Welsh. He was living in George Street, and when surrounded by the waters from the tidal wave the roof was removed by the wind and the walls .... and five children were swept away by the flood. He managed to grab the baby and one of his sons. With them he reached the higher ground, only to find that the baby was drowned but the son was safe. The other members of the family perished. Mrs. Welsh was subsequently found tangled in a fence.

Mr. Benson, who lives opposite Queen's Park, states that the water was eight feet high in the vicinity when the tidal wave occurred and four men who were compelled to leave their homes took refuge in *a tree in the Park and remained there for hours. Mr. Benson was unable to give relief on account of the water being so high around his dwelling.*

FATALITIES

Following is a list of fatalities reported to police up to yesterday:-

Alice Amelia Shanks (37), John Joseph Shanks (# years), Alice Shanks (seven months), wife and family of John Shanks. Cecil Shanks, nine months (son of Frank Shanks).

Robert Morton, engineer on Government steamer Relief, killed.

Mrs Welsh and five children (wife and children of Peter Welsh) drowned.

Richard Henry Francis, killed at Show Ground by collapse of building.

Joseph Carr, drowned by collapse of residence on the town beach.

Geogina Phyllis Renor, 2 months, drowned. It was also reported that three other members of the Renor family are missing.

Edward Hehir, ganger of Pioneer Shire Council, killed through collapse of Hill End School, where he took refuge.

William Coakley, died from exposure. Mr Coakley was one of the first men to cross the Range when Mackay was being settled in the early days: he crossed with the late Mr. James Ready.

THE HOSPITALS

Next to the death roll the story relating to the effect of the cyclone on the hospitals is the most pathetic. At the District Hospital the building suffered severe damage and patients and staff had an experience which they will never forget. At Lister private hospital the roof was almost completely removed and all the rooms flooded. The hospital was full at the time and the doctors and nursing staff had a very trying time to protect the patients until they could be removed elsewhere. At Mrs. Gibbs' private hospital the patients had also to be removed while the rain was falling. This work was carried out expeditiously with the assistance of the ambulance officers, who secured volunteers and in many cases removed patients during heavy rain through deep water on stretchers. To make provision for patients, the Girls State School is being fitted up as a temporary hospital. It might be here mentioned that all the local doctors worked untiringly to relieve the sick wherever they were located.

RELIEF MEASURES

We have not space to record the heroic work done by rescue parties. It became apparent early on Monday morning that prompt relief measures were necessary to succour the homeless and prevent a condition which if left to itself would speedily become deplorable. Following the work of rescuing people from flooded homes, meetings were held to control the food supplies, health, and other vital matters to the afflicted community. The upshot of these numerous conferences was a meeting of citizens at which a series of resolutions were passed controlling the food supplies, the health of the town and as far as possible put a check on the pilfering of iron and other articles that had become notorious. Committees were formed and these, assisted by the police, the military, and medical men, *are now doing what is possible to regulate in as equitable a manner as possible the distribution of food and the protection of inhabitants. At present food tickets are issued daily, covering one days supply of bread and one week's provisions. The meat supply is ample for requirements.*

A source of danger to health of the community is the dead animals that are lying about the municipality, but especially in the South Ward where losses in stock, mostly horses, is very great. Hundreds of fowls were drowned, as well as many goats. In connection with pilfering, the police are doing what they can to bring the offenders to justice and have already made an arrest. The way that iron from about the town was illegally removed and the articles that floated into River and Victoria Streets stolen was disgraceful.

THE RAILWAY SERVICE

The railway station buildings and rolling stock suffered as a result of the cyclone. On the line connecting the station with the wharves two covered wagons were blown over, while at the station, and a great deal of damage was done. When interviewed yesterday the Traffic Manager (Mr J. Strachan) stated that about one-third of the goods shed remained, while other buildings were partially or wholly unroofed. A quantity of sugar in trucks in the station yards was badly damaged. A number of homeless people arrived at the station on Monday and were accommodated in railway carriages. On Wednesday, 23rd, a train left for the country in hopes of reaching Newbury. The first obstruction met with was the shelter shed at Ooralea, which was overturned and thrown on to the main line, but not seriously damaged. The sheds at Te Kowa, Alexandra and Pleystowe were smashed and debris had to be removed from the track to enable the train to get through as far as Pleystowe. Here the Newbury ganger met the train and reported that the line was intact, but the shelter shed at Newbury had been blown over. The train returned to Mackay at .... subsequently one of the railway employees arrived from Garget on the pumper and reported that Cattle Creek bridge was submerged. Mr. Jones (Departmental accountant) arrived from Rocky Dam and reported that on Monday the camp there was partially wrecked by the cyclone, but other buildings were intact. On Tuesday the water came over the walls to a depth of 12 (?) inches and flooded the camp site. Considerable damage was done at Koumala, while at Sarina the quarters and shed were unroofed, also the enginemen's quarters. The damage on other sections of the line was not serious except at Rosella where the shed was unroofed. Serious washaways have occurred on both sides of Bakers Creek, and this cannot be repaired until the flood waters subside. Nos 1, 2 and 3 spans of the concrete piers of the Sandy Creek bridge were wrecked, and the train service to Sarina is suspended until repairs are effected or a diversion put in. A washaway also occurred on the station side of the Kiran bridge, and the train which arrived there on Thursday had to tranship passengers to Mackay. Mr. Strachan said he was in hopes of resuming an ordinary service on this line today. On Monday morning the train from Hatton started away at the usual hour but the line was obstructed to such an extent with fallen timber that it took four hours to go from Hatton to Pinnacle.

There follows a description of the impact of the cyclone on inland areas towards (Finch) Hatton, in other country areas and the impact on the region's sugar mills. It concludes with an account of the impact of the cyclone on Flat Top.

<u>VISIT TO FLAT TOP</u>

Yesterday morning the Harbour Master (Captain E.S. Greenfield) and Mr. P. Steele of the A.U.S.N. Company visited East Point and Flat Top with stores in the motor boat Elenor. At the signal station at East Point the residents had had much the same experience as those in Mackay. The house had been unroofed and the people driven to living quarters in a store room at the rear of the buildings. At

Flat Top similar conditions prevailed and the Superintendent, Mr. Randell, informed the Harbour Master that they had had a very trying time. Portion of the roof of the house disappeared, the flag staff was blown down and the flag room also. The lighthouse had the windows smashed. The tidal wave cleared everything from the shores of the island including the boat sheds, etc.

The remainder of the report deals with the impact in the Mackay hinterland.

This extract from *The Mackay Daily Standard,* Monday, January 28, 1918, describes the use of morse to communicate Mackay's plight to Flat Top and further afield:

The successful signalling from the roof of the Grand Hotel (in Mackay) to the light-house keeper at Flat Top, who was able to transmit the message to steamers fitted with wireless, is our only means of communications with the outside world. The first message, as reported in Saturday's 'Standard', was got through to Flat Top and thence to the "Wyreema" on Thursday night, and was a concise but explicit statement of main facts of the catastrophe by Captain Greenfield (Harbourmaster) to the Portmaster in Brisbane. Last night further signalling was carried out, and the news received is detailed under another heading. The signalling was supervised by Mr. F.W. Boddington (Postmaster) and was carried out by Mr Harvey (telegraphist) assisted by Mr J. Vidulich, who proved himself to be an expert reader of flashes. The signals were in Morse code by motor-car lamp from the roof of the Grand Hotel, the wiring to which from Dr. Stuart Kay's residence was carried out by Messers. Pettigrew (telephone exchange) and R. Smith (line repairer), Dr Kay supplying the electricity for the flashes from his accumulators. Mr Rendell had charge of the signalling at Flat Top.

The following extract has been taken from the log of the Lightkeeper, Flat Top Island and describes the communications with Mackay following the 1918 cyclone. The log was supplied by Captain G.F. Long of the Company of Master Mariners of Australia.

The Master of the "Arawatta" decided to wait until the next morning in the hope of hearing some word from Mackay, and his judgement was sound in this respect, as soon after dark a flash of light could be seen from the direction of the town (on the 23rd), and the first signal being startling enough, it being S.O.S. meaning undoubtably 'send immediately assistance'.

The difficulty now experienced was that although I could see the light from the lamp quite plainly, it being a powerful lamp, they could not see my answering light. The signal after being given many times was followed by the words 'disastrous floods', but although I waited around all night the weather did not clear sufficiently for them to see my light, and I received no more details.

At 9 p.m. I signalled the following message to the "Arawatta" – "Mackay is morsing disastrous floods – weather is too bad to get remainder of message – please wire Brisbane to get assistance at once". This the ship promised to do, and the knowledge that the outside world knew of our straits made our minds a little easier.

Soon after 7 p.m. (on the 24th) the message was received from Mackay which disclosed how serious matters were. The message was as follows – "Cyclones, floods and tidal wave losses 14, bodies recovered, all wharves and sugar stores have collapsed. Relief, Quasha and Brinnawar sunk. Tay, Apa and Pelican ashore. Mackay is on military rations and only ten days food supply on hand. No lighterage plant available. The country has suffered badly. It is urgent that Government send steamer capable of entering river with supplies of food also large quantity of galvanised iron and timber. All buildings, Pilot Station and Signal Station unroofed and vacated by crew. All marks except lighthouse destroyed and no means of replacing same. Boatshed and all plant completely swept away". This message was from the (Mackay) Harbour Master to the Port Master, Brisbane.

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